NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AH-64 APACHE COST REDUCTION

by

Daniel R. Short

March 2000

Thesis Advisor: David F. Matthews

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The Total Ownership Cost Reduction (TOCR) Program was implemented to assist the Program Manager (PM) in upgrading components with significant life-cycle costs. Neither a formal database tracking system for corrosion nor a funded program for updating corrosion-susceptible parts exists. In 1996, at Hunter Army Airfield, Georgia, replacement of corroded gearboxes on the AH-64A Apache Helicopter accounted for $1.12M, yet went unnoticed due to the lack of a comprehensive database. The Apache PM experiences difficulty in taking full advantage of the TOCR program because of application and funding uncertainties. Corrosion of the Apache's driveline components merits overhaul-procedure modifications under the TOCR program. However, the lack of database tracking and inadequate TOCR program funding discourage PM use. This thesis researches component database tracking and TOCR funding to facilitate the PMs reduction of the Apache's life-cycle costs.

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AH-64 APACHE COST REDUCTION

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Submitted in partial fulfillment of the
requirements for the degree of

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from the

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ABSTRACT

The Total Ownership Cost Reduction (TOCR) Program was implemented to assist the Program Manager (PM) in upgrading components with significant life-cycle costs. Neither a formal database tracking system for corrosion nor a funded program for updating corrosion-susceptible parts exists. In 1996, at Hunter Army Airfield, Georgia, replacement of corroded gearboxes on the AH-64A Apache Helicopter accounted for $1.12M, yet went unnoticed due to the lack of a comprehensive database. The Apache PM experiences difficulty in taking full advantage of the TOCR program because of application and funding uncertainties. Corrosion of the Apache's driveline components merits overhaul-procedure modifications under the TOCR program. However, the lack of database tracking and inadequate TOCR program funding discourage PM use. This thesis researches component database tracking and TOCR funding to facilitate the PMs reduction of the Apache's life-cycle costs.

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I. INTRODUCTION

A. OVERVIEW

This thesis investigates and analyzes the costs associated with replacing corrosion-susceptible parts on the AH-64A Apache Helicopter and the PM's responsibilities and capabilities to effect those changes. The thesis explores the cost-effectiveness of a dedicated cost-tracking effort and modifying or re-engineering those items found to be economically impracticable to continue replacing. Finally, this thesis will examine the processes involved in submitting the component modification through one of the cost reduction programs in order to gain requisite funding. The following is an overview of the political and economic influences affecting the current situation.

The political environment within the military has changed significantly during the last 10 years. The Soviet's "Warsaw Pact" has disintegrated due to economic instability; the bipolar threat from which our National Defense focus was derived, is gone. The new, emerging threat to our nation and the world is unfocused and multi-faceted, and this change has resulted in a modification of our national defense strategy. That strategy is now geared more toward Operations Other Than War (OOTW), Conflict Resolution, and Peacekeeping Operations, rather than the traditional strategic global threat. U.S. Lawmakers have responded to taxpayer desires for smaller military expenditures and have

reduced the funds available for equipment appropriations. The "peace dividend," sought by the public since the fall of the Berlin Wall, has forced the President and Congress to cut back on discretionary spending, resulting in significant shortfalls in military budget funding allocations. The most significant reductions in funding have come in new weapon systems research, development, and acquisition.

The Army's Tables of Organization and Equipment (TOE), which authorize the personnel assigned to various units, have shrunk by an average of 10% in the last twelve years, while deployments and missions have increased. Personnel shortages only further aggravate the challenges of maintaining, without the needed spare parts, older equipment that is more prone to breaking down. Military maintenance budgets were cut substantially, but commanders working with older equipment still have the requirement to achieve readiness rates. Equipment, personnel, and training fund shortages come at a time when the threat has mandated an increase in Operational Tempo (OPTEMPO), a full level of magnitude increase over that of twenty years prior.

The defense contractors, whose existence depended greatly on the American military, have been "let down" with the loss of our large-scale threat. Many of them, seeing the "writing on the wall," have moved away from defense production and begun focusing on commercial technologies. The competition among defense contractors, which drives

prices down and fosters affordability, is diminishing. The United States has seen widespread consolidation of defense industries during the past few years. During the late 80's, there were 50 defense firms that, driven by low profits and an instinct for survival, merged into what are now the top five defense firms. This consolidation was fueled by cuts of more than 70% in defense spending since the end of the cold war. (Ref 1)

Profits continue to diminish for the major defense contractors; Lockheed Martin Marietta, the world's largest defense contractor, made only 1.7% profit for Fiscal Year 1999, sending their stock prices plunging to only 25% of this value two years earlier. (Ref 2) The GAO reported that more than $2 billion in government savings resulted from these defense industry mergers during the period from 1996 to 1999. Although consolidation is helping with our goals of modernization and lowering costs in the short-run, the long-run costs of reduced competition in the defense industry could have far-reaching impacts on future costs and readiness. A recent publication listed the defense aerospace industry dead last, 173 out of 173, in terms of profitability. (Ref 3)

Today, high technology weapon systems with state-of-the-art hardware and software are difficult to pursue. Military equipment manufacturers are no longer a significant force in advanced technology. Contractors are increasingly divesting themselves from strict military production. It is fueled by an excellent economy and the unwillingness

of contractors to subject themselves to the massive paperwork inherent in defense contracts. (Ref 4) The result is that equipment appropriations will be increasingly tougher to justify as competition diminishes and prices increase.

These appropriations shortfalls will limit new acquisitions and mandate the continued utilization of older equipment. In many cases, equipment scheduled for phase-out will be used long after its scheduled service-life is over. The UH-1H utility helicopter, scheduled for phase-out in 2000, has received a service-life-extension until the year 2017. (Ref 5) The B-52, fielded in the 1960's, still remains in active service today. The AH-64, fielded in 1986, is scheduled to remain in service until 2020; plans already exist for extending this date. (Ref 6) Extending fielded equipment's life is imperative in light of equipment fielding shortages, budget constraints, and increased maintenance and operational requirements. Reducing costs through re-engineering and modifying components is essential to lower life-cycle costs and maintain readiness.

B. BACKGROUND AND REASON FOR STUDY

In February 1996, I was the maintenance commander for the 1-3d Aviation Regiment, AH-64A attack helicopter battalion, at Hunter Army Airfield, Savannah, Georgia. The Class IX Air budget (Aviation Spare Parts) represented over 90% of the battalion's operating budget. Because

I was responsible for this budget, I focused intently on significant cost-drivers. Examining the major cost-drivers revealed that replacing gearboxes (nose gearboxes, tail-rotor gearboxes, intermediate gearboxes, and transmissions) accounted for more than $1.12M in fiscal year 1996. The primary cause for gearbox replacement was corrosion. Similarly the Texas National Guard's Houston-Ellington Field averaged one gearbox per month turned in for corrosion. (Ref 7)

A standard of 80% in return credits is normally expected on most high-dollar components turned in for repair, including the $1.12M we spent to replace the corroded gearboxes. Extensive corrosion and the inability to rebuild many of these components were suspected to be the reasons the unit received a refund credit of less than 30%. The difference between an 80% credit and a 30% credit represented $560,866 for the corroded gearboxes. Because of the cost significance, corrosion became a major issue for our maintenance department and internally to the unit.

Measures were taken to mitigate the effects of corrosion and lower AH-64 life-cycle costs. We increased inspection requirements approximately 20% and doubled washes for the airframe, drive gearbox components, and the engines. Despite our aggressive efforts, we witnessed few returns at unit level. Our poor results led us to determine that nothing could be done to fix the source of the problem. However,

our efforts focused only on surface corrosion prevention, through washing, inspection, and approved corrosion preventive compounds. With our limited resources, we were unable to stop the source of the corrosion.

Recently, Corpus Christi Army Depot formed an Airframe Condition Evaluation Team (ACE Team), which predominantly monitors airframe corrosion. Although the team realizes the need to broaden the database collection effort to focus more on component failure, current funding limitations prevent this crucial step. The team, limited in funding and scope, agrees that analyzing corrosion on aviation components and their resultant life-cycle costs would be invaluable in identifying alternative procurement methods to reduce overall life-cycle costs. (Ref 8)

Further research revealed that Program Managers have access to funding for reducing life-cycle costs, under a program called the Total Ownership Cost Reduction (TOCR) Program. Within this program, the Operations and Support Cost Reduction (OSCR) program focuses on measures to reduce costs on items already fielded using an "upgrade through spares" approach. After many conversations with personnel in the Apache Program Manager's office and at Corpus Christi Army Depot, it appears that although these programs (TOCR and OSCR) exist for life-

cycle cost reduction, they are not effectively targeted against the AH-64 cost-driving components.

When this thesis research began in September 1999, the intention was to gather all data on AH-64 gearbox failures and analyze it to determine source causes of corrosion and trends dealing with age, environmental factors, aircraft hours, and manufacturing processes. This approach required gathering quantitative and qualitative data ranging from the inception of the Apache program in 1986 through the current year, including cost data on various types of repairs.

Requests for information to Corpus Christi Army Depot (CCAD), Apache PM, Operations & Support Cost Reduction (OSCR) program, US Army Total Ownership Cost Reduction (TOCR) program, and B-17 Apache item manager (the office which handles all gearbox contracts and disposition), all revealed similar information. Sufficient qualitative and quantitative failure data and repair cost information on the AH-64 series gearboxes was not available. All of the contacted organizations agreed that information on gearbox failures would be invaluable in analyzing root cause failures and could help solve the problem of high failure rates. They felt, however, gathering such information was impractical due to the associated collection and processing costs.

C. RESEARCH QUESTIONS

1. The primary research question

- What is the effectiveness of the Total Ownership Cost Reduction program (TOCR) and the Operations and Support Cost Reduction (OSCR) program in lowering component corrosion-related life-cycle costs on the AH-64 Apache.

2. Subsidiary research questions

- What is the current status of database tracking on AH-64 Apache components in the Army, and what metrics are commonly used to analyze this data?
- To what extent were metrics used in the past, today, and planned for the future to prevent component losses, and what metrics could be developed that would provide better insight to the problem and help avoid or reduce future life-cycle cost-drivers?
- What is the current corrosion cost per AH-64 Apache airframe annually, and what is the overall cost to Army aviation; what is the impact on readiness caused by losing these components to corrosion?

- What are the short-term and long-term costs and benefits of re-engineering or modifying those significant cost-driver components?
- What are the procedures for determining the costs of re-engineering a previously fielded part to increase its reliability?
- What responsibility and incentives does the AH-64 PM have for funding upgrades to a fielded system and how is that responsibility affected when the fielded system is subsequently upgraded? What is the source of that funding, and how would funding an upgrade affect the user's operations and support costs?

D. SCOPE OF THE THESIS, LIMITATIONS AND ASSUMPTIONS

Scope: The scope will include (1) a literature review of published books, periodicals, and web sites to gather all information on AH-64 component corrosion; (2) phone and personal interviews with individuals working at the TOCR, OSCR, PM, CCAD, and Navy corrosion offices concerning pertinent organizational and political influences on cost reduction programs; (3) a review of generic corrosion texts to gather information on various types of corrosion and their causes, and appropriate preventive measures; (4) an extensive search of all databases and metrics being used to track significant cost-driver failures and their

root causes; (5) development and analysis of significant cost-drivers associated with corrosion on the AH-64 Apache; (6) a review of successful and unsuccessful cases of total ownership cost-reduction and operations and support cost-reduction; (7) recommendations to decrease life-cycle costs and increase maintenance readiness for the AH-64 program; (8) an evaluation of the likelihood of success of the component corrosion upgrade as a cost reduction program candidate.

Limitations: Although every attempt was made to gather the most accurate field data for Apache gearbox corrosion, there is no formal system to collect this data at or above the unit level. Much of the data had to be extracted from DA Form 2410 database (Component Removal and Repair/Overhaul Record), which is a logistics tracking database that provides only a reason code for component removal. Aviation and Missile Command's (AMCOMs) field data office provided the database. This information is currently used only for the logistical tracking of aircraft components to verify that location information and time-scheduled overhauls are documented properly. The analysis in this thesis was conducted from DA Form 2410 data to determine the root cause of failures.

Assumptions: Although each gearbox is affected differently by corrosion, approximately 20% of the gearboxes contain corrosion when turned-in for other than corrosion failure codes. This assumption is

based on the estimates of organizational maintenance personnel, intermediate level maintenance personnel, and Corpus Christi Army Depot personnel who rebuild the components. There is no other failure-data source information available within the Army other than the DA-2410.

E. DEFINITIONS AND ABBREVIATIONS

AAE	Army Acquisition Executive
ABC	Activity Based Costing
ACE	Airframe Condition Evaluation
AH	Attack Helicopter
AIMI	Aviation Intensively Managed Items
AMC	Army Material Command
AMCOM	Aviation and Missile Command
AMDF	Army Master Data File
AMMC	Army Material Management Center
AOG	Aircraft On Ground
APA	Aircraft Procurement, Army
APB	Acquisition Program Baseline
ARL	Aviation Research Laboratory
ASA(RDA)	Assistant Secretary of the Army (Research Development and Acquisitions)
AVN	Aviation
AVSCOM	Aviation Systems Command
C3S	Command, Control, And Communication System
CCAD	Corpus Christi Army Depot
CECOM	Communications and Electronics Command
DA	Department of the Army
DA DB	Department of the Army, Database
DBOF	Defense Business Operating Fund

DoD	Department of Defense
FCR	Fire Control Radar
FFP	Firm Fixed-Price
FMC	Fully Mission Capable
FYDP	Future Years Defense Plan
GAO	Government Accounting Office
GCSS	Global Combat Support System
HAAF	Hunter Army Airfield
HQAMC	Headquarters Army Material Command
HTI	Horizontal Technology Integration
IEWS	Intelligence Electronic Warfare and Sensors
IGB	Intermediate Gearbox
IPT	Integrated Product Team
LNG	Left Nose Gearbox
LRU	Line Replaceable Unit
MDA	Milestone Decision Authority
MS	Microsoft
MSC	Major Subordinate Command
MTBF	Mean Time Between Failures
MTOE	Modified Table of Organization and Equipment
NICP	National Inventory Control Point
NPV	Net Present Value
O&S	Operations and Support
OER	Officer Evaluation Report
OMA	Operations and Maintenance, Army
OMB	Office of Management and Budget
OOTW	Operations Other Than War
OPTEMPO	Operations Tempo
ORD	Operational Requirements Documents
OSCR	Operations and Support Cost Reduction
OSD	Office of the Secretary of Defense
PEO	Program Executive Office
PM	Program/Product Manager
PMOLCS	Program Manager Oversight of Life Cycle Support

POM	Program Objectives Memorandum
PSA	Pre Shop Analysis
PVS	Prime Vendor Support
QC	Quality Control
RCM	Reliability Centered Maintenance
RMS	Reliability, Maintainability, Supportability
RNG	Right Nose Gearbox
RTD&E	Research Technology Design and Evaluation
SARDA	Secretary of the Army, Research, Development and Acquisitions
SBCCOM	Soldier Biological Chemical Command
SCMA	Sustainment Cost Management Annexes
SH	anti Submarine Helicopter
STAMIS	Standard Army Management Information System
STRICOM	Simulation, Training, and Instrumentation Command
TACOM	Tank and Automotive Command
TMDE	Test Measurement Diagnostic Equipment
TOC	Total Ownership Cost
TOCR	Total Ownership Cost Reduction
TOE	Table of Organization and Equipment
TRG	Tail Rotor Gearbox
USASAC	United States Army Security Assistance Command
VE	Value Engineering
WC	Working Capital
WCF	Working Capital Fund
WIPT	Working Integrated Product Team
XMSN	Transmission

F. ORGANIZATION OF STUDY

The methodology used in this thesis research includes the following steps:

Conduct literature and Internet searches of books, magazine articles, CD-ROMs, and other library information database resources. Conduct a thorough review via email and telephone interviews to identify all information available on life-cycle cost reduction programs and data collecting metrics currently being used by the Program Manager (PM), Corpus Christi Army Depot (CCAD), and operational units. Investigate what incentives exist for PMs to use the TOCR program. Gather data on successful and unsuccessful cost reduction cases. Analyze failure data using Microsoft Excel, Crystal Ball, and Excel Pivot tables to determine applicable data correlation. Use existing data and trends to conduct trend analysis and simulations to project future impacts on cost and readiness.

G. BENEFITS OF THE STUDY

The study identifies pathology within the current cost reduction programs as they apply to AH-64 Apache corrosion. A further benefit is an analytically rigorous estimate of the corrosion within the AH-64 community and the associated cost of treating that corrosion versus

understanding of how the TOCR program works and how to more effectively use the program to lower life-cycle costs. Additionally, those items which are significant corrosion cost-drivers on the AH-64 Apache will be more clearly evident and will be presented to the Program Manager as candidates for product improvement under a cost reduction program.

H. CHAPTER SUMMARY

Contingency missions and global deployments continue at the highest peacetime rate in United States history. The American Armed Forces are under constant pressure to get missions done "better, faster, cheaper" in the quest for global peace with an affordable price tag. Equipment fielding rates have slowed in response to congressional budget reductions and as a result, combat units are maintaining older pieces of equipment for longer time periods. Lowering total ownership costs by effectively targeting programs for cost reduction is essential in the quest for fulfilling the political goals of this country while maintaining a balanced budget.

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II. OVERVIEW

A. INTRODUCTION

Chapter two explores the need for cost savings within the Department of Defense and the impact of the Total Ownership Cost Reduction (TOCR) program on those savings. This chapter will explore how the TOCR program evolved, identify its goals, and determine what effect the TOCR program has on Program Manager's responsibilities toward system development.

Total Ownership Cost Reduction is a concept whereby the costs of a program are considered from cradle to grave, not just the program's procurement cost. The TOCR program is gaining momentum as legacy systems become a larger percentage of the weapons arsenal that we will have to use to fight and win on tomorrow's battlefield. The Army has been working total ownership cost reduction since mandated by Dr. Gilbert Decker (ASA (RDA)) in April 1997. (Ref 9) Total Ownership Cost (TOC) means that all costs associated with operating, modifying, maintaining, supplying, and disposing of a weapon system are considered in its acquisition. For a cost reduction program to be effective, it must work with both developmental and legacy systems.

The driving force behind the necessity to lower life-cycle-costs is the smaller defense budget combined with the decreasing proportion of

that declining budget dedicated to procuring new weapon systems. Operations and Support (O&S) costs are increasing in relation to procurement expenditures, yet are shrinking in terms of absolute dollars. The combination of reduced budgets for O&S and significantly reduced procurement, demand lowering life-cycle costs while increasing reliability, supportability, and maintainability (RMS). Figure 1 depicts the shrinking procurement and O&S dollars.

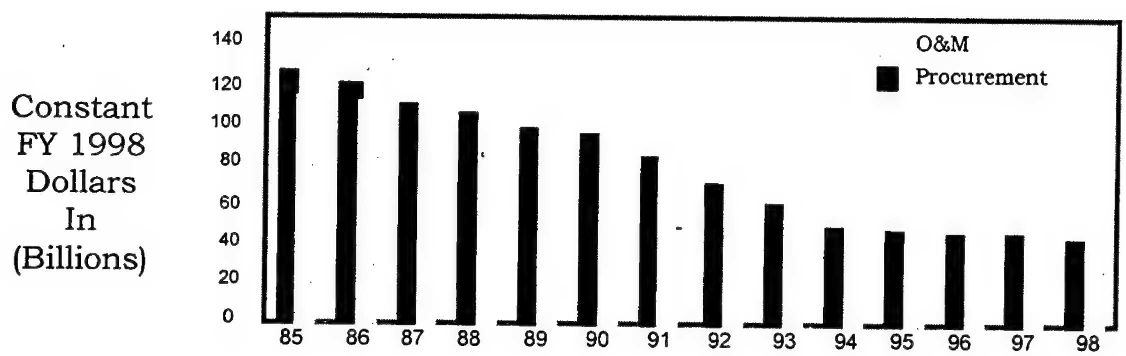

Figure 1, Annual Procurement vs. Operations & Maintenance (O&M) Spending, Source: LTC Brad Naegle, NPS Instructor

As new weapon systems procurement slows, our dependence on legacy systems increases. Program managers are now being tasked with ensuring that both new and legacy systems reduce total life-cycle costs.

B. THE EVOLUTION AND STRUCTURE OF THE TOTAL OWNERSHIP COST REDUCTION PROGRAM

Historically, when a program has been defined by cost, only the equipment investment costs are considered. The diminished number of new acquisitions has increased emphasis on maintaining older equipment in service for a longer period of time and has changed the definition of program cost. (Ref 9, 10, 11, 12) The Office of the Secretary of Defense (OSD) and the Assistant Secretary of the Army (Research, Development and Acquisition) (ASA (RDA)), are demanding a reduction in Operating and Support (O&S) costs. These offices have mandated that there be a significant reduction in ownership costs, and that program's cost be reported in terms of total-system-life-cycle-cost and not just initial investment costs. (Ref 11)

Dr. Gilbert F. Decker, ASA (RDA), dispatched a memo on April 29, 1997, detailing the plan for a program of Total Ownership Cost Reduction (TOCR). The program goal is to reduce system ownership costs to help the Army meet its modernization objectives. Mr. Decker's goal was to establish O&S cost reduction as an acquisition priority. TOCR is based on the concept that a piece of fielded equipment costs more than simply the investment costs; ownership costs include operating, modifying, maintaining, supplying, and disposing of

weapon/materiel systems. (Ref 11) In April 1999, the program officially stood up and came under DA management when the program's charter was signed on October 26, 1999. (Ref 13) Colonel James Stevens was the charter Officer-in-Charge (OIC); he was replaced by Colonel Robert Corlew who currently heads the organization.

The TOCR program places the Program Managers (PMs) in charge of the total life-cycle for assigned systems, including responsibility and authority for planning, programming, budgeting, and executing the sustainment funds associated with their systems. (Ref 14) The Under Secretary of Defense (Acquisition & Technology) (USD (A&T)) actively supports charging the PMs with sustainment responsibilities and authority. Performance evaluation reports for Program, Project, Product, and System Managers will document progress in reducing O&S costs for their assigned systems.

In a subsequent memorandum, dated June 18, 1998, Mr. Keith Charles (Deputy Assistant Secretary of the Army (Programs and Policy)) described total ownership cost reduction as being "paramount to the Army at a time when the Army is facing declining resources." (Ref 15)

When the TOCR program was initiated, it lacked clear requirements and guidelines. As a result, it failed to achieve those goals that were established. To accelerate the momentum of the Total Ownership Cost Reduction program and move towards implementing the

requirements of the April 29, 1997, memorandum, Milestone Decision Authorities (MDAs) and Program/Project/Product/System Managers were required to complete the following actions by September 10, 1998:

a. Exploit opportunities for cost reduction using the Operating and Support Cost Reduction Program (OSCR), Modernization Through Spares (MTS), Prime Vendor Support (PVS), Fleet Management, Horizontal Technology Integration (HTI), and POM Process Life-Cycle Cost Reduction Proposals. (Ref 16)

b. Develop Sustainment Cost Management Annexes (SCMAs) to Acquisition Strategies. Because of inadequacies in present cost accounting systems (CAS), tracking the actual O&S cost elements associated with a system is impossible. SCMAs were tasked with determining departments' top-ten O& S cost drivers and devising plans to reduce costs and measure progress. PM accountability is limited to reducing those O&S cost elements that he/she could reasonably be expected to influence. PMs are to report barriers to TOC reduction and recommend ways to minimize or eliminate them. (Ref 16)

c. Include program-related O& S costs in the Acquisition Program Baseline (APB). The APB should reflect projected reductions to be attained by executing the PM's O& S cost reduction plan, as detailed in their SCMAs. (Ref 16)

d. MDAs will, prior to approval of any modification or upgrade, review O&S cost reduction plans for programs and systems beyond Milestone III. (Ref 16)

e. PMs should establish O& S Cost Reduction Integrated Process Teams to facilitate planning, executing, and measuring the actions contained in the SCMA. (Ref 11,16)

The newer guidance clarified the requirements somewhat, but momentum was still not strong. In April, 1998, Secretary of Defense Cohen submitted *Actions to Accelerate the Movement to the New Workforce Vision,* to Congress in order to create a "real revolution in business affairs." (Ref 17) Secretary Cohen identified five actions:

1. Reengineer product support to use best commercial practices
2. Competitively source product support
3. Modernize through spares
4. Establish program manager oversight of life-cycle support (PMOLCS)
5. Expand PVS and virtual prime vendor arrangements.

The fourth action was mandated because of the uncertainties concerning whether or not PMs could implement a cost reduction program. On August 28, 1998, the USD (A&T) established the Program Manager Oversight of Life-Cycle Support (PMOLCS) Study Group in accordance with Cohen's directives. (Ref 16) The group was formed to

determine whether or not Program Executive Officers (PEOs) and PMs were able to adequately control O&S costs and reduce TOC. A ten-month study, concluding in June of 1999, determined that PMs and PEOs lack the ability to control a long-term, sustained effort to reduce the costs of their systems without a substantive change. Among other issues cited, many PMs wanted to eliminate the "50-50" rule, which requires public depots to conduct half of the depot-level work for a given program. Although this request brought about strong protest by members of Congress, communities with depots, and logistics communities, the DoD feels that empowering PMs and allowing them this flexibility may lower life-cycle-costs. Because of the PMOLCS's findings, they developed two products and made three recommendations.

The first product is the "Section 816(a) Report" which designates ten key programs across the DoD, and annually reports to Congress the PM's success in reducing costs for those programs. The PMOLCS recommended facilitating the PM's success by: increasing program manager oversight in visibility and control of product support costs, implementing formal commitments for product support through cooperative agreements or competitive awards with private-sector organizations, improving the program's funding stability to capitalize on public and private long-term capital investments, and finally, improving

product management of life-cycle support by managing cultural changes in the public and private sectors.

The second product is a memorandum outlining the testing of PM oversight ideas. (Ref 18) The PMs are to draft plans which address program management, cost, and recommendations for policy, regulation, organization, and statute changes. These plans must then be forwarded to the TOCR Working Integrated Product Team (WIPT) for review.

The PMOLCS's three recommendations were based on the suggestion that the TOC of a new weapon system be a critical parameter. Those recommendations include a requirement for the war-fighter, acquirer, and supporter to agree on TOC critical parameters in the Operational Requirement Document (ORD). Second, the PMs will test concepts and implied policies, practices, and procedures of the PMOLCS and report by January 1, 2002. Finally, the PMOLCS recommended that the chair of the TOCR WIPT monitor the tests, review results, and develop proposals and policies to ensure that necessary cultural changes occur to implement the PMs oversight of life-cycle support. (Ref 16)

TOCR program funding uses a designated TOCR POM line to review/fund TOC reduction initiatives. The intent of the program is to fund the initial investment in process or product improvement and either recover the cost savings from the PM, or allow the PM to build an internal Working Capital Fund (WCF) to facilitate internal funding of

further cost reduction initiatives. The status of the PM's program POM funding lines remains a question as it is still uncertain whether or not POM lines are debited in the current year, budget years, program years, or not at all. Currently the AMC intends for only the investment cost to be repaid, and desires a sharing arrangement for savings between the PM, AMC, and the Department of the Army, while the DA argues that it should receive all cost-savings. (Ref 19) Although all TOCR initiatives are encouraged throughout the Army and can be submitted by anyone, funding is prioritized to those programs that were designated as pilot programs by DoD and the individual services. The process of O&S cost reduction under TOCR is depicted in Figure 2:

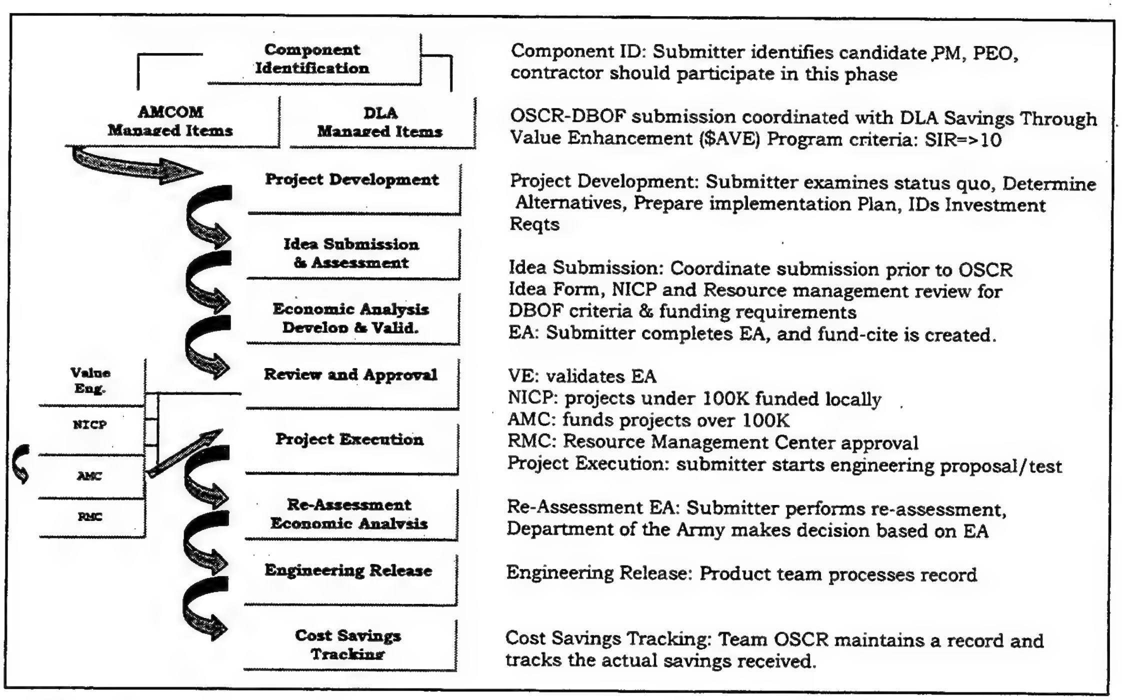

Figure 2, Cost-reduction submission process, Source: Author using charts found on OSCR Web site http://www.pica.army.mil/esd/OSCR/oscr1.htm

C. COST REDUCTION IN THE MACRO ENVIRONMENT (ARMY)

The TOCR program divides initiatives into four broad categories: investments, process improvements, industry partnering agreements, and technology. Each of these categories examines issues and initiatives to lower life-cycle costs while improving readiness and reliability. Within each category, each sub-category is addressed using one of the many cost reduction programs.

- Investments
  - POM 00-05
  - Operating and Support Reduction Program (OSCR)

Investments currently look at how to fund a POM line through appropriations for each of the services. A request for $500M for FY 2001 was downgraded in a POM promise compromise to $53M, leaving funding for only a few of the 138 proposed initiatives. (Ref 20) The program is also exploring the feasibility of providing PMs with organic OSCR Working Capital Funds (WCF).

- Process Improvements
  - Top Ten cost drivers
  - IPTs: SARDA, AMC, PEO-MSCs
  - Cradle-to-Grave Acquisition Strategy
  - Paperless Contracting
  - Activity-Based Costing (ABC)

Process Improvements explore how the Top-Ten cost-drivers from each service are addressed. The Apache is the number one program for the Army and first on the list of the Army's cost-drivers. The entire

concept of Cradle-to-Grave Acquisition Strategy is based on the TOCR philosophies. The strategy focuses on lowering life-cycle-costs during Concept Exploration (CE), long before production begins.

- Industry Partnering
  - Prime Vendor Support (PVS) Apache
  - Fleet Management
  - Kiowa Warrior engine rebuild

Industry Partnering includes PVS, the Apache Program Manager's focus for cost-cutting, which is currently on hold due to a policy decision on working capital funds and failure to achieve required A-76 waivers. Prime vendor support promises cost reduction through:

- Firm-Fixed Price (FFP) contract per flying-hour with shared savings
- 16% reduction in flying-hour program cost, to include:
  - 20% increase in flying-hours with 25,000 hour surge capability
  - $320M of Apache modernization
  - Life-of-contract performance warranty/obsolescence avoidance
  - Increased technical field support
  - Follow-on contract with performance-based guarantees
  - System configuration management with refresh of War Reserve

- Technology
  - Horizontal Technology Integration (HTI)
  - Test and Measurement Diagnostic Equipment (TMDE) Embedded Diagnostics
  - Modernization through spares

Technology includes HTI, which guarantees the Army maximizes buying power by combining requirements and developing a single

process or product that meets the war-fighter's needs. Modernization through spares focuses on acquiring technologically-improved replacement parts and reducing ownership costs. (Ref 11)

TOCR initiatives can be submitted to the TOCR offices Alexandria VA., and via the Internet. As of 14 March 2000, 138 initiatives exist with 117 of them entered through the Internet web site www.sarda.army.mil/tocr/default; 129 initiatives have been evaluated. The six funded initiatives were funded by other than the TOCR dollars, as the FY 2000 TOCR POM line is unfunded. A breakdown of initiatives includes 48 initiatives submitted by the various PEOs, 87 by AMC, and 3 by individuals outside of the PEO/AMC arena. Figure 3 depicts the initiative status for all TOCR submissions to date:

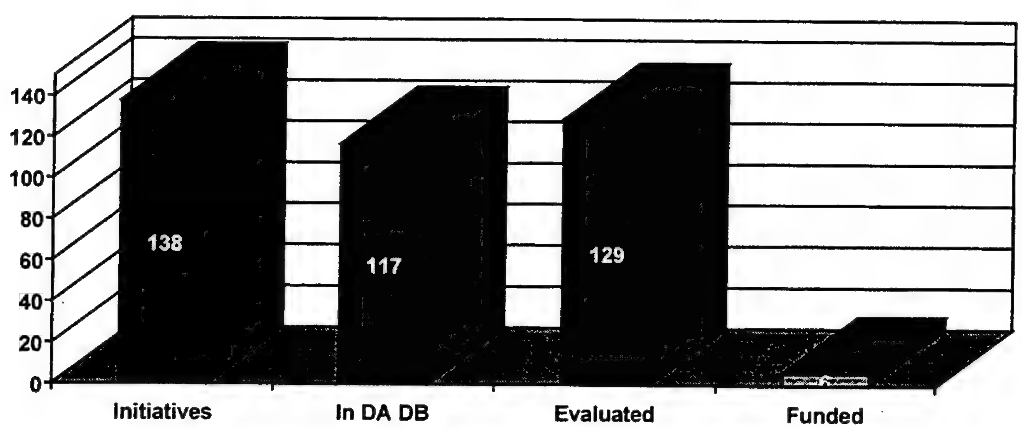

Figure 3, TOCR submissions as of 13 March 2000,
Source: DA TOCR Office from Ref 19

The PM Apache, and PM Commanche, who still fall under the PEO, have submitted 18 initiatives to date. Because there is no funding in the

POM for FY 00, the intent is to secure funding under a future POM line. AMCOM's 19 initiatives include legacy systems like the Blackhawk and OH-58. The following two charts breakdown the TOCR initiative submissions from the AMC and PEOs respectively:

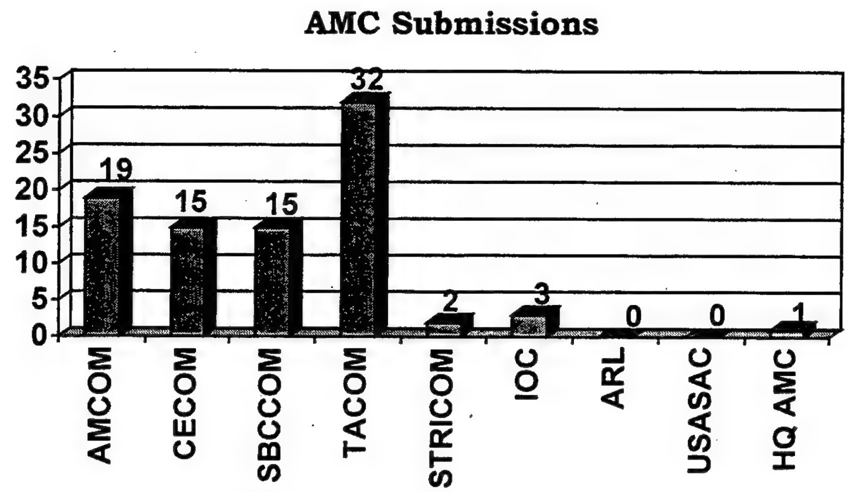

Figure 4, AMC TOCR submissions, Source: DA TOCR Office

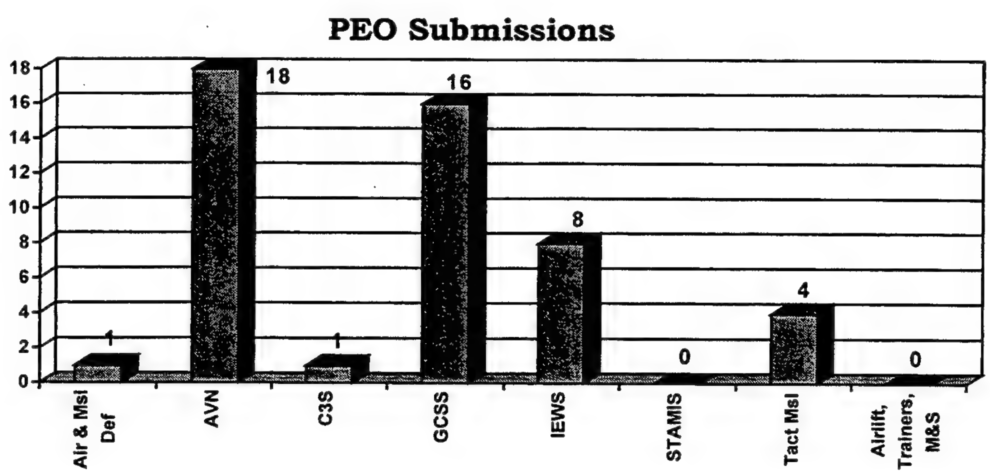

Figure 5, PEO TOCR submissions, Source: DA TOCR Office

D. COST REDUCTION IN THE MICRO-ENVIRONMENT (AH-64 CORROSION)

As of the time of this publication, there were no AH-64 Apache corrosion initiatives in progress under any of the TOCR programs. A review of a recently-published paper, which focused on "estimation of cost of corrosion on the Apache helicopter" recommended that "at this time, it is not recommended to make any major investments in reduction of corrosion cost for the Apache system." (Ref 21) Despite this finding, that same paper stated that "no effort has been made to determine life-cycle corrosion control costs." (Ref 21) The Program Manager has very little information on corrosion due to the 1989 deletion of database tracking which supported the Reliability-Centered Maintenance program. A PM must respond to pressing issues of which there is knowledge; when there is no information that a problem exists, as is the case with corrosion, action can not be taken.

E. IMPACT OF OSCR FUNDING ON POM LINE AND UNIT MAINTENANCE BUDGETS

According to the TOCR office, the intent of the TOCR program is to fund cost reduction initiatives from a cost reduction POM line containing Army Working Capital Funds (WCF). The funds provided from this WCF are supposed to be used for cost reduction, then, once life-cycle cost

savings are realized, the WCF in the TOCR POM line is reimbursed. The PM should then realize cost-savings and build an internal WCF to fund future cost reduction initiatives. The TOCR office has recommended a sharing of cost-savings between AMC, the initiative originator, and the DA. However, because of the DA's current requirement to recoup all cost-savings, the AH-64 PM was concerned about debiting his supported commanders' (Operations and Maintenance Army) (OMA) appropriated funds in the "current year," should the cost-savings from an OSCR submission be expected in less than three to five years.

F. THE NEED FOR AN ALTERNATIVE APPROACH

The Total Ownership Cost Reduction program is emphasized by the Department of Defense and the Secretary of the Army as a priority to ensure readiness and modernization for the Army's future. However, funding issues with the TOCR program seem to be sufficiently confusing that although personnel within the Apache Program Manager's office try to provide required data to the TOCR office, the program is evolving rapidly and guidelines change. Understanding and taking full advantage of potential program benefits is difficult. They believe that should the PM use cost-reduction funds to increase reliability, the funds to pay for the upgrade could be taken from the field commanders' maintenance budgets before any cost savings accrue. No office, including the TOCR

office in Alexandria, Virginia, could fully explain either how or what funding pays for initiatives, or how this funding will affect either the PM's or the field commander's budgets in future years. The uncertainties in initiative funding and in cost-reduction payback are forcing PMs to wait until issues dealing with initiative priority, funding, and POM impact, are resolved. PMs are hesitant to accept the risk of funding a cost-reduction initiative that may be debited from their RTD&E, OMA, or Procurement funds, only to have the DA reduce operations and support dollars for the field commanders in the current year or future years' POMs.

Numerous memorandums were written about the TOCR program to clarify requirements enumerated in previous memorandums. Momentum is said to be gaining, but not quickly enough. Attempts have been made to accelerate momentum by making the PMs fully responsible for the life-cycle costs of their program. It is difficult to hold an individual accountable for a program that will not reveal its life-cycle costs until years after the former Program Manager has either moved to a new job or retired

If TOCR is to work, the information on how to use the program and the affects of funding must be disseminated effectively to all PMs. The rules and guidelines must be clear and succinct, and PMs must be adequately incentivised to use the program by receiving benefits, such as sharing cost savings.

G. CHAPTER SUMMARY

The TOCR program is still relatively new. Although gaining momentum, it has neither been adequately funded nor is it well understood. Many PMs perceive the processes and procedures as complex, and do not fully understand either how to use the program or how it will affect their budgets or the budgets of the field commanders they support. PMs are hesitant to use the program because of uncertainties about the impact on the Future Years Defense Program (FYDP), their Aircraft Procurement, Army (APA) funds, and commanders OMA funds. The TOCR program is clearly needed to reduce the life-cycle costs of our new and legacy systems. With adequate funding and clarification of procedures, it should provide the means for modernization within the allocated budget.

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III. METHODOLOGY

A. OVERVIEW

The DoD mandated PMs to reduce their program costs by 20% to cover future forecasted shortfalls in appropriated dollars. The AH-64A PM looked to Prime Vendor Support (PVS) to be the focus of his cost-cutting initiatives. PVS removes the flying-hour budget and aviation spare parts from the unit-level and provides them with flying-hours and a required readiness rate at a reduced fixed-cost per hour. Contract issues and Working Capital Fund (WCF) complications have put PVS on hold while the PM searches for other cost-cutting initiatives.

Pathology within the Army and the AH-64 Apache program is hidden because of the lack of a comprehensive failure data collection system. An investigation into a suspected problem with gearbox corrosion revealed that a significant amount of corrosion exists on magnesium castings.

The recurring problem of excessive corrosion on aircraft magnesium gearboxes surfaced on the AH-64A Apache Attack helicopters at Hunter Army Airfield (HAAF) Savannah, Georgia, from 1996 to 1998. At the CCAD, pre-shop analysis inspection team records revealed that a startling 55% of the tail-rotor gearboxes repaired at the Depot for various

mechanical failures also required corrosion repairs, and additionally, in more than 60% of those cases, corrosion was the *only* defect. (Ref 22)

Presentation of the corrosion data assembled by this researcher to the engineers of CCAD revealed two final amazing facts. First, the magnesium extracted in the United States and used in the Apache gearboxes is high in iron content, making it extremely susceptible to corrosion. Second, the AH-64 gearboxes being overhauled and those being manufactured by new contracts are still being produced with a "corrosion protective" procedure, known since the late 1970s to have been ineffective in corrosion resistance. Upgrading the magnesium coating on the gearboxes provides an inexpensive option for the PM to quickly modernize the defective components, significantly increase the gearboxes' MTBF, and substantially lower life-cycle costs.

B. METHODOLOGY OF ANALYSIS

The 1-3d Attack-helicopter Battalion at Hunter Army Airfield, Georgia, was forced to carefully analyze its flying-hour budget allocation in the summer of 1996, as a result of both restrictions in operational flying-hour funds and a high OPTEMPO. From February 1996 through May 1997, the unit had replaced nine nose gearboxes, two transmissions, and five intermediate and tail-rotor gearboxes on 24 Apache helicopters because of corrosion. The unit's supply management

conducted an audit of records and determined that the turn-in credit received on the magnesium gearboxes averaged only about 30%. On most other high-dollar aviation spare parts, as was the case with the 1-3d Attack-helicopter Battalion's aviation repairable-exchange program, the unit normally expected, and programmed for, an 80% return credit on all parts turned in for repair. The significant reduction in return credit amounted to a $560,866 loss on only 16 gearboxes in one year.

The unit altered its corrosion preventive maintenance to include increased fresh water washes to rinse off the salt debris caused by the close proximity to the Atlantic Ocean, and supplementary inspections of critical components to detect and treat corrosion in its early stages. The unit's aggressive steps in hindering corrosion may have done some limited good, however, there was insufficient data upon which to base reasonable proof because there was limited time to observe the effects. As a result, no notable difference in corrosion prevention was detected during the period from September 1997 to January 1998. Although there was a significant problem with corrosion, it appeared to be a result of design defects within the components, rather than a problem with organizational maintenance procedures.

Almost two years later, an attempt to gather preliminary data to examine the extent of corrosion on AH-64 gearboxes Army-wide, revealed there was no formal database collection system for component failures.

A common misconception among logisticians is that there exists a current database capturing the cause of faults, its cost, and the resultant downtime for high-dollar aviation components. The information was needed to validate the corrosion problem and confirm the findings of the 1-3d Aviation Regiment. In order to determine the significance of the corrosion found at HAAF, the first step was to contact the Program Manager's office in Huntsville, Alabama, and request any and all available database information. Only the DA Form 2410 (Component removal and repair/overhaul record) was available to provide any information. A request for a printout of the entire AH-64 Apache history for turn-in of the four types of gearboxes for any corrosion-related codes, including failure codes 170-Corrosion, 240-Flaking, and 520-Pitted, produced the following table:

Corrosion removals by Part Number

TABLE OF PN BY FCODE

Nomenclature	PN (COMPONENT PART NUMBER) Frequency	170	240	520	Total
Transmission	7-311310001-37	22	1	1	24
Transmission	7-311310001-39	1	0	0	1
LEFT NOSE GB	7-311320001-7	3	0	0	3
Int GB	7-311330001-3	49	0	2	51
Int GB	7-311330001-5	11	0	1	12
T/R GB	7-311340001-5	64	0	4	68
T/R GB	7-311340001-7	5	0	2	7
Total		155	1	10	166

FCODE (FAILURE CODE)

CORRODED	170
Flaking	240
Pitted	520

Source: Chuck Wright, AMC OSCR Team, AH-64 PM Office
Table 1, OSCR Team's 2410 Report - As of October 1999

The table indicates that a total of 25 transmissions, three nose gearboxes, 63 intermediate gearboxes, and 75 tail-rotor gearboxes have been removed from aircraft for at least one of the three corrosion failure codes since the Apache program began in 1986. (Note: there are two different part numbers for each gearbox, except the nose gearbox.) The data captured by the DA Form 2410 indicated that only three nose gearboxes (one of the four types of magnesium gearboxes) had failed for corrosion in the seventeen-year history of the Apache program. Three nose gearboxes removed for corrosion represents approximately .1% of the nose gearboxes removed from aircraft. (Ref 6).

Because the reported corrosion was such an infinitely small percentage of the total turn-ins, it would clearly not cause alarm to either a PM or to an item manager. It did, however, cause suspicions to rise in the unit, which not only believed there was a problem with corrosion, but also that there was a problem with the reporting system as well. The 1-3d Aviation Regiment in Savannah turned-in nine gearboxes for corrosion in 1996, which represented over 50 % of their gearbox malfunctions in that one year alone. There was a significant deficiency in the information the 2410 system had reported. The PM's office confirmed that the information sent, although appearing too low, were the figures reported by the 2410 system. The unit's proximity to the ocean justified the data being somewhat higher than the average, but

should be well within an order of magnitude. However, the 2410 report was at least one order of magnitude low.

A request for additional data to AMCOM's field data-collection office revealed a far more significant amount of corrosion than the PM's 2410 data indicated. The new data provided a basis from which the extent of corrosion could be more accurately measured. Correlation effects for reported faults were estimated and validated by unit Technical Supply personnel and engineers at CCAD. Their assumption was that there were fault categories, i.e. contaminated oil, leaking, low grease/fluids, etc., which were highly related to the incidences of corrosion. Interviews with Quality Control (QC) personnel, Technical Supply personnel, and engineers and inspectors at CCAD suggested that approximately 20% of all gearboxes removed from the aircraft were affected to some extent by corrosion. (Ref 7, 23, 24, 25, 26, 27, 28, 29, 30, 31) It was further estimated that a significant number of the gearboxes removed for various mechanical failures were actually failures *resulting* directly from corrosion.

The estimate of 20% corrosion was adjusted by analyzing data found in the Pre-Shop Analysis (PSA) logbook at the CCAD rebuild and overhaul facility. (Ref 22) The first data analyzed was the tail rotor gearbox, as it was the first section of the logbook that was available. The logbook entries were input into Microsoft Excel and then a pivot-table

was used to determine correlation between corrosion and all other defects. (See Appendices B, C) If there were multiple entries for a single failure, and corrosion was also found with that particular failure, then a determination of correlation was made and possible cause-effect relationships established. Interestingly, many of the same failures that were reported by the engineers and quality control personnel as being related to corrosion were proven to be statistically significant in the pivot-table analysis as having a high statistical correlation.

After extensively analyzing the tail rotor gearbox, similar relationships between failures in the right and left nose gearboxes, intermediate gearbox, and transmissions were hypothesized. Examining the PSA logbook indicated that corrosion occurred less frequently in the other gearboxes than in the tail-rotor gearbox; consequently, corrosion estimates on the respective gearboxes were appropriately adjusted downward.

The historical cost of Apache corrosion was determined by taking historical figures for gearbox overhaul and repair cost, and plotting them against the number of gearboxes turned in for corrosion and corrosion-related faults. Interestingly, the 30% credit the 1-3d Aviation had received for turning-in gearboxes was not low. The unit had not turned in exceptionally "bad" gearboxes; all units in the Army received the same credit and paid the same Stock Funded Depot Level Repairable (SFDLR)

rate for overhaul. The extensive and costly overhaul rate for gearboxes across the Army was driven by contract costs, which were in turn based on the previous year's contract costs. Those costs increased significantly from 1998 to 2000. Although the ratio of rebuild cost to turn-in cost had not changed significantly, the increase in the contract rate had nearly doubled the user rate for CCAD overhauls. (Ref 32)

In determining the total extent of Apache corrosion Army-wide, trend analysis of the previous ten-year's data indicated increases from one to four and a half percent per year in corrosion. The trends, determined separately for each gearbox, were extended out twenty years and plotted against the increasing costs to overhaul the various components in order to determine the overall costs of AH-64 corrosion.

The general trend in the contract costs for gearbox repair also revealed an increase. During the three most recent years, the average increase in contract costs was 35%. Some contract costs had increased by more than 80%, while the cost of the intermediate gearbox overhaul contract had decreased by 7%. (Ref 32) There was no historical data going back more than three years for overhaul contract rates. The item manager believed the last three years represented non-typical increases in contract costs and therefore the escalation rate for contracts was estimated to be five percent for both the past ten years and for the future twenty years. Five percent is below the recent gearbox contract's average

annual escalation, but seemed to "best fit" the estimated long-term values and was in line with standard contract escalation rate. Cost savings will be significantly larger then those calculated should higher escalation values be validated. The upward trend in gearbox failures was plotted against the escalation of contract costs, and a long-term estimate for the repair costs of gearbox corrosion failures was determined. (See Appendix A)

This data was presented to the CCAD engineers for evaluation and validation. Upon learning of the significant failure rates and trends for the magnesium gearboxes, the CCAD drive-train engineers gathered in a round-table discussion to consider possible causes. During this discussion, one engineer revealed that the magnesium used in the gearboxes is high in iron content, causing it to corrode at an accelerated rate. (Ref 28) Another engineer stated that the magnesium was not protected from corrosion by a resin-based coating, but rather was anodized per the original design specifications from the early 1970s. (Ref 31) The specification for magnesium coating needed to be upgraded to protect the magnesium more effectively. They suggested using the newest resin coating, called Rockhard. This resin coating is used by the U.S. Navy and is slated for use by the Blackhawk program for their magnesium gearboxes. (Ref 25, 28, 31)

The following is a cost analysis of changing the manufacturing and overhaul procedures for the tail-rotor gearbox from the current Dow 17 anodized process to resin coating with Rockhard. Direct labor and direct materials required applying Rockhard vs. Dow 17 were compared. Table 2 justifies investing in a switch to Rockhard because of the modest investment costs over continuing to use Dow 17.

Description	Rockhard cost	Dow 17 cost	Differential Cost
Cost per hour for labor	$ 93.98	$93.98	
Hours to apply	2.00	0.67	1.33
Labor cost of Job	$187.96	$62.65	$125.31
Materials	$197.50	$10.00	$187.50
Total Cost	$385.46	$72.65	$312.81
Surcharge rate AMMC	18%	18%	
Surcharge Cost	$ 70.92	$13.37	$ 57.56
Total Price	$456.38	$86.02	$370.36
Price Increase			**$370.36**

Source: Author, from information provided by Ref 28, 42

Table 2, Cost increase for tail-rotor gearbox to Rockhard coating

The increase in resin coating costs was added to the overhaul contract costs for the CCAD, and those resin-coated gearboxes were projected to corrode at a *conservative* one-eighth the rate of Dow 17-coated gearboxes. A new plot of the decrease in failures due to corrosion was plotted against the increasing costs of rebuild to reveal the new cost of corrosion for the next twenty years of the Apache program. (See Appendix A) Finally, the costs in the out-years were corrected for the time value of money according to the Office of Management and Budget's

(OMBs) figure of 5.7% to reveal the Net Present Value (NPV) for each gearbox. Summaries of the NPV for each gearbox are contained in Table 6, page 67.

C. THE AH-64 PM'S NEED FOR COST REDUCTION

The AH-64 is here to stay. The aircraft has no scheduled phase-out date because it is the most venerable attack helicopter in the world, and there is nothing on the drawing board scheduled to replace it. (Ref 6) The AH-64 PM is responsible both for sustaining the Alpha model and developing the Delta model and the Longbow, which includes the Fire Control Radar (FCR). Because its service-life will be no less than another twenty years, the PM has a vested interest in ensuring life-cycle costs remain as low as possible.

When Dr. Gilbert F. Decker dispatched his landmark memo detailing the plan for the reduction of total ownership costs, his goal was to contribute these savings to help the Army meet its modernization objectives. This new strategy would be implemented by forcing PMs to take responsibility for the total cost of their systems, including the responsibility and authority to plan, program, budget, and execute the sustainment funds associated with their systems. (Ref 11)

When the DoD directed each service to name their top ten programs, the Army named the Apache as one of their top ten because it

is the most expensive program to date. The ASA (RDA) requirement for the designated programs was to reduce logistics support costs by 7% by FY 2000, 10% by FY 2001, and 20% by 2005. (Ref 33, 34)

The Prime Vendor Support program was intended to provide an increased OPTEMPO capability, lower flying-hour costs, and remove much of the managerial budget burden from the operational battalions. The program remains on hold, pending the determination of who will fund the massive quantity of Line Replaceable Units (LRU) and the major class IX spare parts that must be purchased from the Army's Working Capital Fund. According to the Deputy Apache PM "The process is waiting for approval of alternatives before modifying the contract to account for new policy guidance." (Ref 37) LTG Kern added that "approximately 50% of the Apache's O&S dollars pay for programs other than the Apache," and that the PVS program hadn't taken this indirect-funding into account. (Ref 35)

The OSD, supported by the ASA (RDA), stated that the PM's Officer Evaluation Report (OER) would reflect the success of their program in terms of life-cycle costs. (Ref 36) Momentum continues to push toward making the PMs responsible for all aspects of their programs, even those aspects that will not be fully-evident until long after the PM is gone. Since 1995, the Apache PM has been aggressively pursuing O&S cost reduction and will continue to pursue cost reduction even if the PVS

initiative is defeated. (Ref 37) With TOCR success now a part of every PM's OER, and PVS on the sidelines, the Apache PM needs to find new cost-reduction initiatives including gearbox corrosion reduction.

D. FAILURES IN THE FAULT REPORTING SYSTEM

The General Accounting Office reviewed information processing and database collecting systems across the Department of Defense (DoD) in 1992 and determined that the Army's Reliability Centered Maintenance (RCM) program was the best DoD program of its kind. The RCM database tracked failure data and used the information to determine root cause analysis. The RCM program's expansion toward root-cause analysis ended in 1993, when it was determined that the program was not cost-effective and suggested the existing 2410 system was adequate. The RCM program reportedly cost $3M per year. Therefore, the Aviation Systems Command (AVSCOM) discontinued RCM program funding in favor of the DA Form 2410 system. AVSCOM believed that the DA Form 2410 system was less expensive but effective substitute for RCM. (Ref 38, 39, 40)

The 2410 system catalogs components removed from aircraft. Junior enlisted personnel fill out the form with an entry that records what failure the component was suspected of, but not necessarily what was actually wrong with it. The form was designed for logistics tracking

only. Less than five percent of the forms are updated at the component repair level when that component is disassembled and the true cause of failure is determined. For example, when a gearbox is removed for an "oil leak," and upon removal the component is found to have significant corrosion, the fault code listed in *Block 10. Failure Code* will read "oil leak" and not the corrosion that actually produced the leak.

E. FAILURES IN THE GEARBOX SPECIFICATIONS AND MANUFACTURING PROCESS

In 1972, the AH-64 Apache was in Concept Exploration. During this era, specification development included corrosion resistance measures for the magnesium gearboxes. The Military Specification (Mil Spec) for magnesium corrosion protection at that time was Mil M 3171 Type III; also known commercially as Dow 17. Although it was the state-of-the-art for 1972, significant advancements in magnesium corrosion resistance prevention have been made since then. Dow 17 is unlike most currently used magnesium protective coatings, which provide both an oxygen and a moisture barrier. It is merely an anodizing process and alters only a few microns of the magnesium's surface. (Ref 41, 42) By 1978, magnesium protection had evolved beyond merely etching the surface in order to change its surface properties. Resin coatings were being used extensively, both by the Navy in their fixed and rotary-wing

assets, and by the Blackhawk utility helicopter to prevent the exposed magnesium surfaces from returning to an oxide. In spite of this, the corrosion-resistance specifications for Apache gearboxes remain unchanged to date. The AH-64 gearboxes being overhauled at CCAD are still treated with Dow 17, the process known since the late 1970s to be ineffective in corrosion resistance.

Today, all the AH-64As are being converted to either AH-64Ds or to AH-64 Longbow models. With these various configurations, the Apache is the most advanced attack helicopter platform in the world. Resultantly, there is no projected replacement for the Apache. The end of the Apache's service-life has not yet been scheduled, mandating life-cycle cost reductions for this aircraft.

Discard rate: An average of up to five percent of the nose, intermediate, and tail rotor gearboxes are discarded due to excessive corrosion (Ref 31). This value can not be accurately determined because there are no records kept on gearbox discard rates. For the nose gearboxes and the tail rotor gearboxes, excessive corrosion is the primary cause of gearbox housing failures significant enough to render the component non-economically repairable. For the transmission housing, the discard rate is estimated to be only one or two percent, with the corrosion found primarily at the mating surfaces of the generator input at the transmission's front surface. Although the discard rate for

transmission housings is relatively low, when compared to the Navy's 50+% discard rate, it merits consideration. Procurement costs can be twice the overhaul cost and discards reduce spares availability.

Gearbox coatings ordinarily make stripping previous protectant difficult. The Navy SH-60s and the Army's UH-60s changed from Mil R 3034 to Rockhard, realizing they had to modify their overhaul and rebuild procedures which involved removing oils, dirt, and old resin coating from gearboxes. The process of removing the Mil R 3034 resin coat from the interior of the gearboxes, to re-coat them with the new Rockhard resin corrosion preventive, is fairly time-consuming and costly. The old resin coat must be removed on the Blackhawk gearboxes because the temperature at which Rockhard is applied is high enough that it destroys the Mil R 3034 coating. Further, the chemicals used to prepare magnesium for Rockhard resin can harm the existing Mil R 3034 resin. (Ref 42) Finally, Rockhard has better adhesion properties than Mil R 3034 and any residue loosened in the overhaul process may break loose and clog the oil straining system, causing component failure. Stripping Mil R 3034 also involves several hazardous chemicals including chromic acid, which requires costly compliance with strict EPA waste elimination procedures. (Ref 42)

For the AH-64 program, this resin coating removal procedure is not a factor. The existing Dow 17 is only an anodized coating and as such,

requires only routine gearbox cleaning before applying Rockhard coating. (Ref 42) The magnesium coating procedure is even less expensive when the gearbox is manufactured in compliance with a specification calling for Rockhard, requiring completing the coating procedure during the original manufacturing process. (Ref 42) (See Table 2)

Army policy on Rockhard: Currently, the Army's official policy is to use Rockhard only in cases where a gearbox is repaired for significant corrosion. As of March 2000, not one Apache gearbox has yet been coated with Rockhard resin coating. (Ref 27, 28) The procedures have already been written to enable CCAD to replace Mil M 3171 with Rockhard. The facilities and equipment are in place, and the personnel have already been trained in the procedure. When the learning curve is accounted for in estimating the labor required to apply the Rockhard resin coating to the Apache gearboxes, the costs will ultimately decline as the workforce becomes more efficient.

F. ECONOMIC ANALYSIS OF THE OVERHAUL PROCEDURE CHANGE

The Costs of the Status Quo

In 1997, the cost of overhauling a tail rotor gearbox was $15,145. The most recent Army Master Database File (AMDF) cost data on the

same gearbox is now $19,364. (Ref 32) Below table 3 depicts the 1997 rebuild cost for the various gearboxes.

Nomenclature	Unit Price	Credit value	Unit Price WC	% cost to Overhaul
Main XMSN	$278,637	$155,479	$123,158	44%
R.H. NGB	$40,001	$22,321	$17,680	44%
L.H. NGB	$36,028	$20,104	$15,924	44%
T/R GB	$34,264	$19,119	$15,145	44%
Intermediate GB	$45,307	$25,281	$20,026	44%
Average	*$ 86,847*	*$ 48,461*	*$ 38,442*	*44%*
Source:	Author from information provided by Ref 32			

Table 3, Gearbox rebuild costs - as of March 1997

The price in the column under the "Unit Price WC" is the cost to the unit working capital fund. The current AMDF rates (as of 7 FEB 2000) are generally higher as reflected in the following table:

Nomenclature	Unit Price	credit value	Unit Price WC	% of new to Overhaul
Main XMSN	$295,880	$169,106	$126,774	43%
R.H. NGB	$ 38,467	$ 9,220	$ 29,246	76%
L.H. NGB	$ 38,467	$ 8,907	$ 29,559	77%
T/R GB	$ 36,384	$ 17,020	$ 19,364	53%
Intermediate GB	$ 48,111	$ 29,494	$ 18,617	39%
Average	*$ 91,462*	*$ 46, 749*	*$ 44,712*	*58%*

Source: Author, from information provided by Ref 32

Table 4, Gearbox rebuild costs - as of 9 February, 2000

The average cost of overhaul exceeds 45% of the unit price, considered by some to be the point at which a component is replaced

rather than rebuilt. Since the costs of overhauling the nose-gearboxes approaches 80% of the unit price, replacing this component with newly-manufactured units must be considered. (Ref 44)

G. CHAPTER SUMMARY

The tremendous discrepancies in the corrosion data provided by the various reporting agencies gives reason for concern. The lack of accurate data collection and reporting means that obtaining reliable information assimilating different pieces of data and comparing, analyzing, and interpolating conclusions from those data. The DA Form 2410 and the Pre-Shop Analysis data conflict on numbers; however, both seem to indicate significant corrosion in Army aviation.

The PM must cut costs to ensure the Apache program survives for the next twenty years. Without PVS, the PM must look inward at ways to cut costs and increase readiness. Data collection will provide the necessary information from which to make the most informed decisions.

Reviewing potentially outdated specifications and standards may yield insight towards finding solutions to existing problems. The current corrosion prevention measures for magnesium gearboxes inadequately protect the Apache in its myriad operational climates. A modification to the overhaul and manufacturing process will protect the magnesium an estimated ten times more effectively. (Ref 41,42) This upgrade will

significantly increase MTBF while lowering costs, all with a minimum initial investment.

This inherent inaccuracy in the reporting system mandated questioning QC personnel, gearbox engineers, component rebuild technicians, and inspection personnel to determine more accurately the extent of corrosion. The general consensus of the inspectors and technicians closest to the removal, inspection, and rebuild process all seem to agree that approximately 20% of all of the magnesium gearbox casings were affected to some extent by corrosion. From these expert estimations, the 2410 data and the PSA logbook are interpreted to determine as closely as possible the raw data.

IV. ANALYSIS AND DISCUSSION

A. OVERVIEW

This chapter analyzes the data and findings presented in chapter three. It attempts to draw logical conclusions based on the relevant field experience, interviews with various agencies, and the analysis of spreadsheet data. The chapter will present the PM's requirement for an accurate database to make informed decisions and the necessity to use that information for cost reduction. The magnitude of the corrosion issue and lack of a comprehensive database is illustrated by comparing the reports of the AMCOM OSCR office within the AH-64 PM, and the research based on analyzing the field data reports, multiple interviews, and CCAD records.

The cost of corrosion in terms of readiness, maintenance at the organizational and intermediate levels, and Depot rebuild costs, is presented for each gearbox. An in-depth economic analysis of the best alternative to the status quo is explored, including a twenty-year projection of the reduction in gearbox failures and the estimated improvement in life-cycle-cost and readiness. Finally, estimates of the impact on operations and support (O&S) Program Objectives Memorandum (POM) funding and impact on the AH-64 PM are explored.

B. THE PM'S RESPONSIBILITY FOR COST REDUCTION

The PMs were charged with the responsibility of lowering life-cycle costs for their programs. This guidance, initiated with Mr. Gilbert Decker's memo in 1997, has been clarified, re-iterated, and re-stated on countless occasions by the OSD, Secretary of the Army, Chief of Staff, Army Acquisition Executive (AAE), USD (A&T), and others. (Ref 9, 11, 12) The PM's are evaluated on their OERs regarding their performance and success in total ownership cost-reduction; yet there is still too little momentum and the desired results remain unattained.

In August 1999, the Program Manager Oversight of Life-Cycle Support (PMOLCS) study stated program managers required long-term, sustained efforts to make the substantive changes necessary to control life-cycle costs. (Ref 16) Issues cited by PMs include their requirement to control Depots. The PMOLCS study group recognized the need for increased cost visibility, funding stability, and the need to manage cultural change in the public and private sectors. Perhaps with the products the PMOLCS developed and their recommendations, the PMs can more effectively control life-cycle costs.

In accordance with OSD directives, the AH-64 PM has aggressively pursued cost reduction. In addition to the [stagnated] PVS program, the Apache PM submitted a number of initiatives to the TOCR office and to

date, not one initiative has been funded because DA TOCR has no POM funds for FY 2000. The initiatives remain at the TOCR office with the hopes of receiving funding in FY 2001, but are only covered by a POM promise tentatively covering 10% of those submissions. (Ref 13)

The DA and AMC continue to battle over the status of benefits recouped from the TOCR program; so far, no definitive guidelines exist. DA's policy is to recoup all savings, offering PMs no incentives to submit initiatives to lower life-cycle costs. For the PM, TOCR funding is high risk. A cost-reduction initiative may not reduce costs, yet the line commander's OMA funds will be debited as if the savings actually took place. The AMC's policy suggests a cost-sharing, which incentivizes PMs by allowing them to realize a portion of the cost-reduction. Clearly, PMs must protect not only their program, but also the field commanders they support. The AH-64 PM strongly supports both, and as such may not be inclined to pursue cost reduction unless these risks are addressed. (Ref 39)

C. THE PM'S NEED FOR ACCURATE INFORMATION

As with all leaders, the PM must have accurate information from which to base decisions. The information provided by the DA Form 2410 is flawed. Many times, the information is inaccurate and there is no additional space for subsequent findings. The entries are not corrected.

As a result, initial incorrect information becomes the permanent record. There is no "corrosion" light on the caution/warning panel of the aircraft to alert the pilot or crew chief to failure, so corrosion is rarely identified; rather, the results of corrosion are identified. The PM needs a comprehensive database with accurately-entered information to make informed decisions. With further development, the RCM database may have provided the information required. The $3M per year cost was considered unaffordable and the program was cancelled. However, it is now clear that the price of not having a comprehensive database is increasing AH-64 O&S expenditures.

D. ACCURACY OF THE DATA

Interviews of personnel: Gathering information from the various agencies within AMC, PM, and the TOCR offices involved interviews with more than 40 people. Although they were each specialized in their own career field, few knew how their position fit into the overall scheme of the problem; this research drew these conclusions. Every attempt to represent interviewee's opinions correctly and accurately was made, however some misrepresentation is possible.

Gearbox analysis: Although all gearboxes were analyzed, in-depth correlation using pivot-table analysis was completed for only the tail-rotor gearbox. Repeating this analysis for the remaining gearboxes was

beyond the thesis scope. The pivot table data was then used to determine fundamental relationships between various turn-in faults and corrosion, through a cause-effect relationship. (See Appendix C)

2410 reporting error: The DA Form 2410 is inherently inaccurate in reporting failure data; it was never designed to isolate fault, rather to logistically track parts. The input data on block 10 (Failure Code) of the DA Form 2410 is filled out by personnel trained in removal and installation; they may not necessarily understand the fault. When the component with 2410 arrives at the CCAD, the 2410 only changed to reflect the findings of the overhaul technician 5% of the time. This inherent inaccuracy in the reporting system mandated that actual failure trends be identified through interviews, pre-shop analysis data, and various statistical processes. The data collected is analyzed using the best available methods and is equivalent to or better than "significant" sample data collection.

E. ACTUAL CORROSION IN AH-64 GEARBOXES

The Program Manager's OSCR office requested a 2410 synopsis of nose-gearbox failures beginning with program inception in 1986. The information provided to that office in October 1999, indicated that since the program began only three nose gearboxes had been removed from Apaches due to corrosion. Although that information was questioned by

the PM's office, they received assurances that the information was complete and accurate.

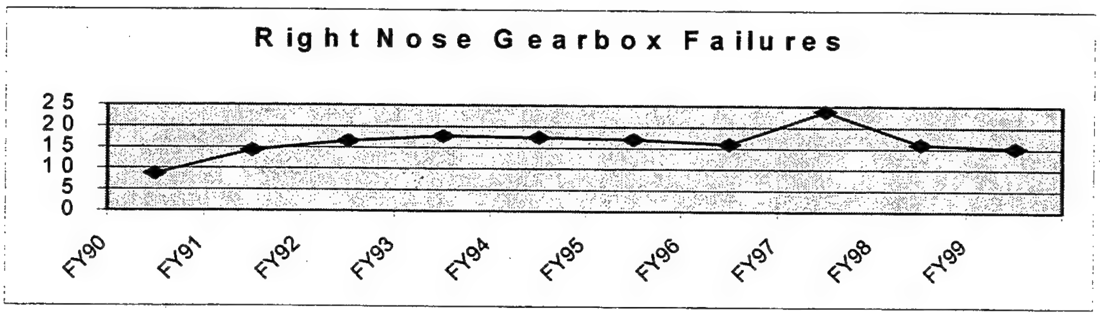
Follow-on research, using a combination of sample data reported by various field units, the AMCOM's field data collection office, and the pre-shop analysis team at the CCAD, revealed that the number of corroded nose gearboxes is estimated to be 428, just since 1990. Unfortunately, no failure data was available for the years prior to 1990. For the purposes of this report, the years prior to 1990 were estimated using the developed trend data from 1990 to 1999. No failures are assumed to occur in the first two years of the program due to the inherent corrosion resistance of new parts. Taking these factors into account, the total suspected corrosion-related nose gearbox failures is estimated to be 1152 gearboxes. The revised information is orders of magnitude greater than originally reported and could clearly alter the PM's decision in prioritizing funding requirements. Table 5 summarizes the failure rates of the various gearboxes and projects failures for the next twenty years:

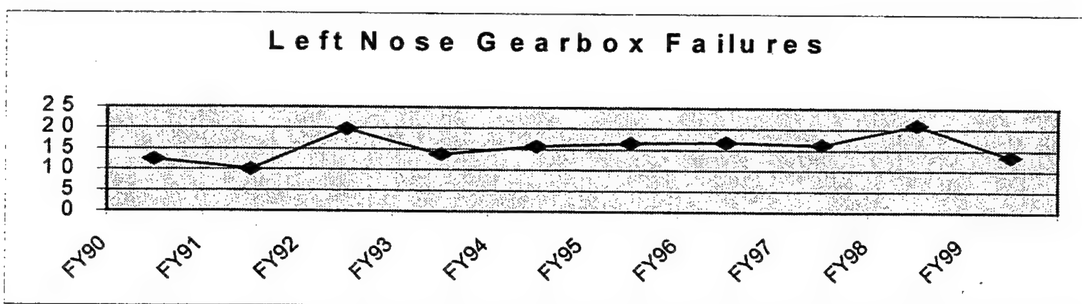
Gearbox	Failures since 1990	Projected by 2020	Failures Reported to PM	Actual:Reported Ratio
Left NGB	156	553	3	52:1
Right NGB	164	599	0	Infinite
Int gearbox	102	427	63	1.6:1
TR gearbox	349	1711	75	4.7:1
Transmission	105	321	25	4.2:1

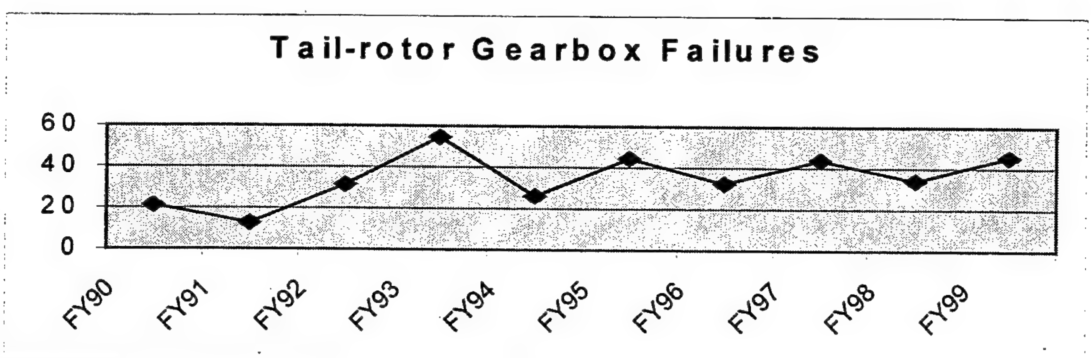
Source: Author, from information provided by Ref 43

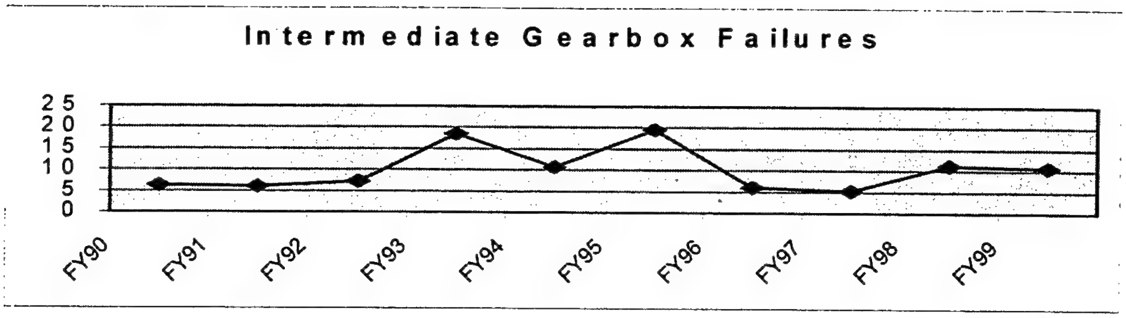
Table 5, 20 year failure projections

The following figures are graphical depictions of the most accurate historical data on corrosion for each gearbox. The relatively consistent spike found between 1992 and 1993 is believed to reflect the extensive inspection and rebuild effort following operation Desert Storm.









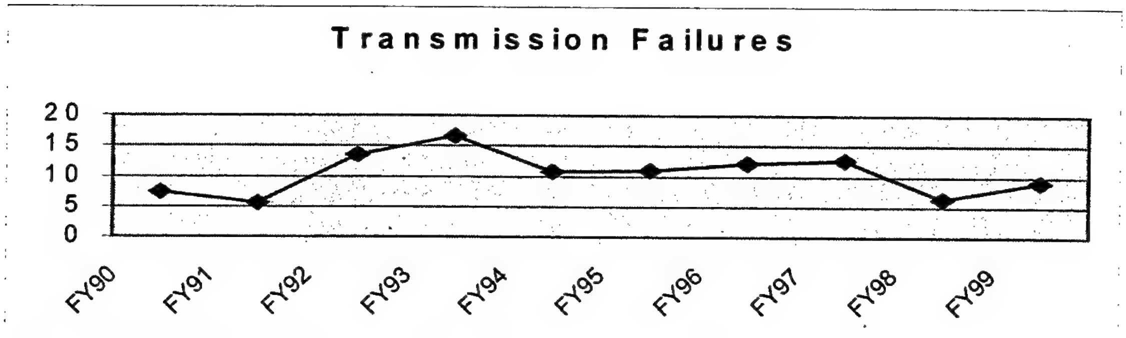


Figure 6, Plots of past nine-year's gearbox failures.
Source: Author, from information provided by Ref 43

The graphs show a general trend of increasing gearbox failures through time. The tail-rotor gearbox shows the clearest increases, averaging a gain in failures of approximately 1.5 gearboxes per year. The tail-rotor gearbox is heavily affected by corrosion and the increase seems to be caused by metal fatigue and removal of material for corrosion repair. The gearbox is limited by the finite number of times it can be repaired for the same failure. A "blend and finish" approach is used to repair any gearbox. Material is removed until healthy unaffected magnesium is found, and then the surface is re-finished by smoothing

and painting. (Ref 28) Additionally, the "Aging Aircraft" syndrome causes metal fatigue, stress fractures, and a general weakening of the material, all leading to greater susceptibility to corrosion.

Transmissions showed the smallest growth in failure rates, increasing only about one tenth transmission annually. This partly reflects an interim corrosion repair done at the CCAD. A slot has been milled in the transmission casing on the bottom side of the generator interface that allows moisture to drain. The drain inhibits galvanic corrosion by reducing the stored water and electrolyte from between the mating surfaces of the Alternating Current generator and the transmission housing. Another possible reason for lower failure rates is the significant cost of the housings. The high cost helps to reduce failures by increasing emphasis on correcting the failures to avoid the significant expenditures.

F. PM OPTIONS FOR REDUCING LIFE-CYCLE COSTS

In determining the most viable alternative to a cost-driver, the PM has the option of using several programs within the overall TOCR program. Value Engineering (VE) offers the PM workshops. If a "suspected problem" has no obvious solution, the VE workshop will come to the site and conduct all necessary research to "reasonably" determine cost savings initiatives. (Ref 46) The PM must fund the workshop and

the programs to implement the cost saving, but owes no other fees or "share" of the cost savings. The PM's Program Objectives Memorandum (POM) line should not be debited for the amount of the savings, so the program recovers all cost benefits. (Ref 20)

Other options include the PMs own Operations and Support Cost Reduction (OSCR) section provided by AMCOM. OSCR investigates potential initiatives and provides suggestions. Initiatives can also come from individuals within the organization or even outside of that organization. Individuals from the military and DoD civilians can submit initiatives directly to the TOCR office via the Internet. (Ref 13)

G. ALTERNATIVES TO REPLACING DEFECTIVE GEARBOXES

In the case of magnesium corrosion, several alternative procurement options were explored, including:

Casting gearboxes in aluminum: Because the gearboxes must be light yet strong, there are only a few viable alternatives to magnesium. Aluminum can be tempered with a heat-treating process to a hardness known as T-6. When hardened to this point, aluminum takes on different characteristics and becomes brittle. There is no requirement for any specific malleability of aluminum, and the T-6 hardness would seem to be appropriate for the application. For any given thickness, T-6 aluminum is stronger and more corrosion resistant, but heavier than

magnesium. This analysis would require tradeoff studies to determine the cost of re-tooling basic castings to facilitate the thinner and stronger aluminum, and further to determine the weight differential between aluminum and magnesium. Because of the potential significant increases in cost for re-tooling, this alternative was considered not economically feasible.

Corrosion preventative sprays: Corrosion X is a spray that provides a moisture barrier and prevents magnesium oxidation. It must be reapplied every month after aircraft washings have been completed and is relatively maintenance-intensive. The cost of the spray is $3400 per barrel. Although effective where applied, it is difficult to apply on many surfaces and leaves hidden mating-surfaces unprotected. (Ref 7)

Carwell is another spray-on corrosion preventative used widely by the Tank and Automotive Command (TACOM) on all ground vehicles in Hawaii. Permission to use this commercial spray-on corrosion preventative for aviation applications is currently being pursued. Due to lack of content disclosure, the product has not yet been approved. (Ref 5) Corrosion sprays has helped slow the corrosion process, but require constant application, are expensive, and are not focused on the cause of the corrosion: failures in the manufacturing specifications. It is equivalent to placing a "band-aide on a large wound."

Refining the magnesium further: Salt water extraction is the primary source of United States magnesium. The extraction process involves using iron as a catalyst to draw the magnesium out of solution. (Ref 28) The magnesium can then be refined to remove the high iron content. Refinement costs are unavailable and therefore limit analyzing this possibility until cost figures can be determined accurately. Refining magnesium merits further research.

Changing to a resin-based coating (Rockhard): Magnesium is reactive when unprotected, especially in highly corrosive environments. The Navy was scrapping 50% of the SH-60B transmissions after only one sea tour. When they switched to the newest resin coatings for their gearboxes (inside and outside), they extended the lives of their gearboxes more than 75% over their former resin coating (which is more than 500% as effective as Dow 17). (Ref 5) The Navy upgrades 100% of their gearboxes during both manufacturing and overhaul to the newest resin coatings because of the tremendous life-cycle cost savings. The Army's policy on applying Rockhard to AH-64 gearboxes is to perform resin coating on gearboxes as needed for corrosion repair. (Ref 28) To date, not one gearbox has been upgraded from Dow 17 to Rockhard. (Ref 27)

H. ECONOMIC ANALYSIS OF THE ALTERNATIVE

The costs of the Status Quo: In 1997, the average cost of overhauling gearboxes was $38,442. (See Table 3, page 52) The most recent Army Master Database File (AMDF) average cost is now $44,712. (See Table 4, page 52)(Ref 32) Gearboxes failure rates continue to increase as contract prices escalate. (See Fig 7 below) Upgrading the gearbox corrosion protection significantly reduces life-cycle costs. Table 6 depicts the net-present-value of the upgrade to Rockhard resin coating: (See Appendix A for charts depicting the cost differentials)

Gearbox	NPV of Mod (Depot Ktr)
Left nose-gearbox	$ 8,277,395
Right nose-gearbox	$ 9,246,013
Intermediate gearbox	$ 3,935,015
Tail-rotor gearbox	$ 18,485,895
Transmission	$ 16,067,714
Total NPV of Overhaul Change	$ 56,012,033

Source: Author, with input from Ref 6, 24, 25, 26, 28, 31, 32

Table 6, NPV of gearbox overhaul procedures change

These values account for Depot contract costs only. They include year-zero expenditures and discount the cost-savings. The costs of Organizational-level maintenance are reflected in the table 7 is explained in depth in Chapter 4, Section J, page 75.

Gearbox	NPV of Mod (Org Maint)
Left nose-gearbox	$ 152,022
Right nose-gearbox	$ 164,391
Intermediate gearbox	$ 183,728
Tail-rotor gearbox	$ 771,659
Transmission	$ 292,057
Total NPV of O-Level change	$1,563,858

Source: Author, from information provided by Ref 32

Table 7, NPV of Organizational-level benefits with Rockhard

Table 8 depicts the overall effect of the significant turn-ins of these gearboxes for repairs, and the resultant shortfalls in availability. (See Tables 3 and 4, page 52 for background)

Nomenclature	optimal	peace	war	shortfall	status	cost to fill
XMSN	135	0	0	135	AIMI	$17,114,490
R NG	145	148	17	-20	AIMI	$ 0
L NG	107	52	20	35	AIMI	$ 1,034,576
TRG	232	0	6	226	AIMI	$ 4,376,264
IGB	98	23	9	66	AIMI	$ 1,228,722
Total cost						$23,754,052

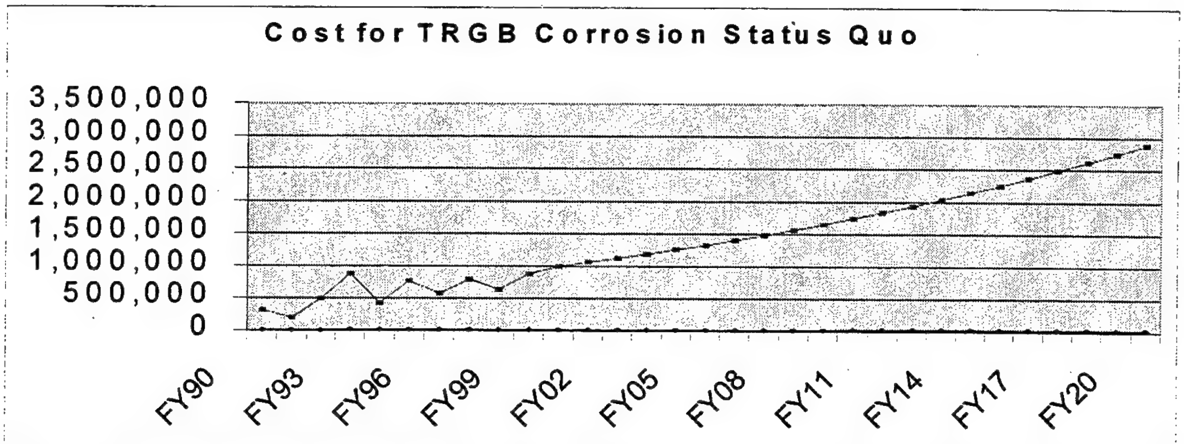
Source: Author, from information provided by Ref 32

Table 8, On-hand gearbox status - as of 9 February 2000

The optimal column is the number of each gearbox that should be available at any given time in a combination of both "peace" and "war." The shortfall includes the number needed to fill to optimal levels. All of the gearboxes, including the right nose gearbox, are currently in an Aviation Intensively-Managed Item (AIMI) status because of their short supply or potential to become limited in availability. The final column is

the cost, at current prices, of repairing all unserviceable gearboxes and filling to the optimal level.

Figure 7 depicts the trend of Tail Rotor Gearboxes (TRG) to fail at an increasing rate due to the "aging aircraft" phenomenon. Figure 7 combines the predictions of future failure rates with increasing contractor gearbox rebuild costs.



Source: Author, from information provided by Ref 43

Figure 7, Gearbox rebuild costs projected through FY 2020

From FY 90 through FY 99, the data points are plotted against actual failure data derived from DA Form 2410 (Record of Aircraft Fault) and the Pre-Shop Analysis (PSA) ledger. Data points from FY00 to FY20 are estimated based on a combination of established failure trends and a projected five-percent yearly increase in the cost of overhaul contracts and a 5.7 percent cost of capital.

During the last three years, significant price increases followed previously stable prices and even occasional cost reductions. Because of the relative inconsistencies, data smoothing was used to "clean" the trends and a five-percent escalation was used. Five-percent was used as it best approximates the long-term trend of the last nine fiscal years.

The costs of the upgrade to Rockhard is as follows in table 9:

Gearbox	Cost of Dow 17	Cost of Rockhard	Cost increase
Left nose-gearbox	93.98	479.44	385.46
Right nose-gearbox	93.98	479.44	385.46
Intermediate gearbox	62.65	385.46	322.81
Tail-rotor gearbox	62.65	385.46	322.81
Transmission	156.63	2,444.90	2,288.27

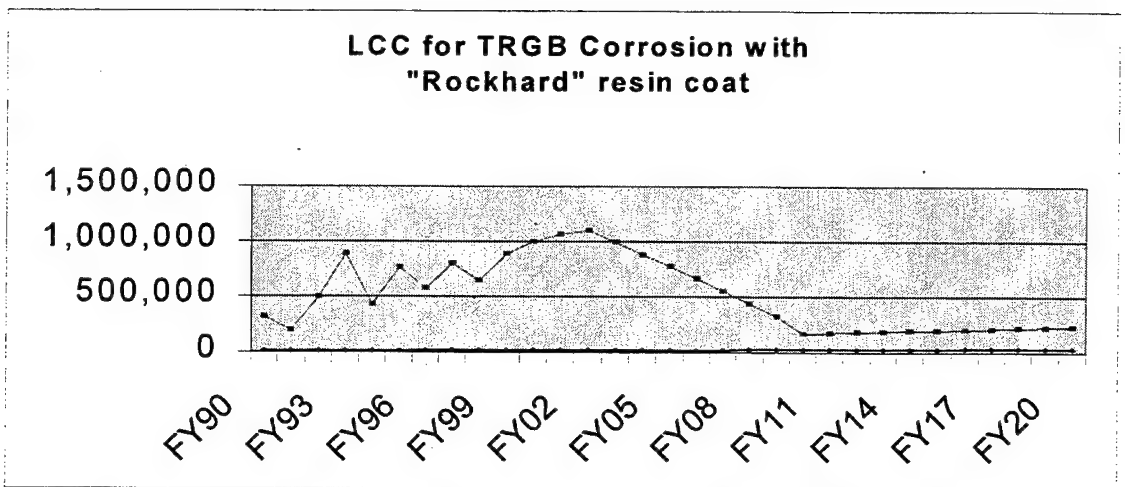
Source: Author, developed by information from Ref 28

Table 9, Cost of process change to Rockhard

The labor rates for the CCAD include all profit and overhead values. The time to apply the materials on a tail rotor gearbox is based on the CCAD's experience in applying the coating to similar-sized Navy Blackhawk tail-rotor gearboxes. (Ref 28) Material costs are based on the Navy's contract price for Rockhard resin at $395.00 per five liters, and a requirement of .5 to 5 gallons per gearbox housing. The cost of preparation is a wash since there are no additional requirements. Regardless of why the gearbox is rebuilt, it will receive an aqua wash or degreaser to remove oils. The Rockhard can be applied right on top of the Dow 17. (Ref 42) A surcharge of 18.4% is levied by Army Materiel

Management Command (AMMC) to pay for their administrative costs. When the cost of the resin coat is added, the overhaul cost is increased by only two percent, from $19,346 to $19,741. When this additional cost is added to the cost of overhaul, and is plotted against the increase in life extension, the benefits of the overhaul program are obvious.

Figure 8 depicts the increased cost plotted against the increased life of the tail-rotor gearbox.



Source: Author, from information provided by Ref 43

Figure 8, Projected life-cycle costs with process change to Rockhard resin

Escalation and the cost of capital values for gearbox overhauls and the resin coating are the same as the "status quo" scenario. Both the costs of gearboxes and the resin coating were escalated at five percent

per year, with the cost of capital at 5.7 percent, per the Office of Management and Budget guidelines.

This program could be implemented immediately, as the entire infrastructure is already in place, including equipment and processes. The payback begins within the first year and gradually increases over the next eight years when annual savings are maximized. By FY08, all gearboxes are overhauled and corrosion is minimized. From this point on, corrosion damage for the tail-rotor gearbox is estimated to cost less than $335,000 per year, down from a projected $4.1M without the upgrade. If the gearboxes are treated at the time of manufacture, the cost savings are even greater, as the cost differential to treat the gearboxes with the resin coat is smaller during manufacturing than during overhaul.

Whether the application of Rockhard is done while the gearboxes are new or when they are being rebuilt at the Corpus Christi Depot, the learning curve dictates that process costs will decrease with time and worker experience. Application of learning-curve theory will eventually drive the cost of resin coating down to little more than the cost of direct materials.

I. COST OF CORROSION: READINESS AND MAINTENANCE BURDEN

Readiness: The readiness requirement established for the Apache is 75%. This means that the aircraft must be in a Fully Mission Capable (FMC) status at least 75% of the month. FMC status requires all aircraft systems to be operational. Gearbox failures will ground an aircraft, and keep it in an Aircraft On Ground (AOG) status for a considerable period of time; the MTBF of each gearbox is critical to Apache readiness. All of the Apache gearboxes remain an Aviation Intensively Managed Item (AIMI) because of their limited availability and their high failure rates. Corrosion is one of the major contributing factors causing the low gearbox availability, especially for the tail-rotor gearbox.

It is difficult to determine the exact extent of downtime caused by corrosion, however it is safe to say that the shortage of AIMI items directly contributes to units' conducting "controlled exchange" (actually "cannibalization") of parts. Controlled exchange involves removing components from one aircraft to trouble-shoot and fix other aircraft. Continually removing and replacing a component causes increased failures due to wear and spoilage, and its resultant downtime. A proactive unit will generally order parts, anticipating failures, and can therefore avoid cannibalization. Because all gearboxes are in an AIMI status and can only be ordered when an aircraft is currently hard-down

waiting for parts, the unit has no choice but to suffer downtime as the parts ordering and delivery process is executed.

In 1996, the 1-3d Aviation held a string of aircraft in an Aircraft-On-Ground (AOG) status for seven months; gearboxes were shifted from one aircraft to another while waiting for additional nose gearboxes to become available. The AIMI system remains in effect for all magnesium gearboxes on the AH-64 because of their critically short supply. Transmissions and tail-rotor gearboxes are in particularly short supply (refer to Table 8, page 68); every request for one of these gearboxes that goes unfilled for 30 days reduces a battalion's readiness by four percent. Four percent for a single gearbox failure is roughly one quarter of the battalion's available downtime. Scheduled maintenance requirements use eight to ten percent downtime, leaving only a sixteen to eighteen percent allowable margin for unscheduled maintenance.

Maintenance: Every gearbox that fails requires an extensive maintenance effort because budget directives force maintenance technicians to spend hours troubleshooting failures to minimize the cost of high-dollar gearboxes. The cost of "trouble-shooting" and cannibalizing to minimize replacement, followed by the required gearbox replacement, is a significant maintenance burden. (See Table 12, page 76, for maintenance replacement costs)

J. ORGANIZATIONAL MAINTENANCE BENEFITS OF CHANGING THE PROCESS

Readiness increases and maintenance hour decreases are two other benefits of increasing gearbox reliability. Tables 10-12 depict the cost-savings in hours of maintenance and their associated dollars. These values were the basis of Table 7, page 68. The Man-hour rate on the "Rate Chart" is determined by AMCOM, based on cost/availability. (Ref 45) Table 10 breaks down the wage rate of an E-5 Sergeant, aviation mechanic in an Apache unit:

Rates based on Aviation E-5	
Military Pay & Allowances	$ 51,962.52
Medical and Training	$ 9,278.59
GI Bill and Misc.	$ 795.97
Total Cost	$ 62,027.18
Productive Hours per Year	768.00
Average Man-hour rate	$ 80.76
Source:	Ref 45

Table 10, hourly wage equivalent of an aviation mechanic sergeant

Each hour on the aircraft requires significant support from Administration, QC, PC, TS, Intermediate level, and transportation before it reaches the Depot at Corpus Christi Army Depot. The "Hour Equivalency" chart depicts the relative hours from various entities that must support each hour of touch labor on the aircraft. One hour incurred by the organizational level (mechanic) requires .1 hour from

administrative offices, .2 hours from Quality Control, etc., with a total of 2.4 hours required for each hour on the aircraft. Table 11 summarizes the time equivalency for 1 hour of "touch-labor" at the organizational level on the aircraft.

Hours on Aircraft Equivalency	
Organizational Level	1
Administration	0.1
Quality Control	0.2
Production Control	0.2
Technical Support	0.2
Intermediate Level	0.3
Transportation	0.4
Total	2.4

Source: Author, developed through work experience

Table 11, Hour-equivalency to "touch-labor" on aircraft

Table 12, "Maintenance Labor Cost" chart depicts the cost to replace each component. For example, it takes three O-level hours to remove and reinstall a tail-rotor gearbox. If each hour of "touch labor" represents a total of 2.4 hours of labor, replacing the tail-rotor gearbox involves a total of 7.2 hours @ $80.76 for a total cost of $581.47.

Type of Component	Hours to Repair	Hour equivalency	Man-hour rate	Replacement Cost
NGB	2	2.4	80.76	$ 387.65
IGB	3	2.4	80.76	$ 581.47
TRGB	3	2.4	80.76	$ 581.47
XMSN	10	2.4	80.76	$1,938.24

Source: Author, from information provided by Ref 23,29,30

Table 12, Component replacement maintenance labor costs

A final measure of savings involves safety. Because of the criticality of each of the drive components, a failure in any single component during a flight has the potential of causing a mishap. The Apache's tail-rotor and intermediate gearboxes, and transmission are non-redundant systems. Any failure of these components could significantly damage the aircraft and cause possible loss of life. Implementing these proposed processes would undoubtedly prevent these tragedies, thereby enhancing unit safety.

K. CHAPTER SUMMARY

The TOCR program seems to be confusing enough that personnel within the Apache Program Manager's cost reduction office do not fully understand it and aren't exploiting program benefits. No office, to include the TOCR office in Alexandria, Virginia, could explain how funding will effect either the PM's or the field commander's future year budgets. The uncertainties are forcing PMs to wait until issues dealing with initiative priority, funding, and POM impact, are worked out.

Economic analysis is a tool that the PM can use to evaluate a suspected problem and compare the costs and benefits of modifications to materials and procedures, to the costs of maintaining the status quo. The Depot program implementation cost is $18,304 during the first year

with a total program NPV of $56,012,033. The organizational maintenance NPV is $1,563,858 with perhaps $2M or more in test flight and trouble-shooting costs.

The cost of the change to the Apache gearbox overhaul procedure is a small investment and has the potential to yield a significant return. Benefits include an almost immediate lower overhaul cost, an increase in the MTBF, a reduction in maintenance requirements and costs, and an increase in operational readiness and safety.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. RESEARCH QUESTIONS AND ANSWERS

The primary research question is:

What is the effectiveness of the Total Ownership Cost Reduction (TOCR) program in lowering life-cycle costs on the AH-64 Apache? The program manager can not utilize the TOCR program to its fullest extent due to a myriad of problems. First, there is no comprehensive database capable of accurately identifying cost-drivers. Second, funds are currently unavailable in the TOCR POM line to support funding of initiatives. Last, uncertainties concerning repaying of incentive funding disincentivize the PM from aggressively pursuing TOCR cost-reduction initiatives.

Subsidiary research questions are:

What is the current status of corrosion database tracking on the AH-64 Apache in the Army today, and what metrics are commonly used to analyze this data? The only system of database tracking in the Army today is the DA Form 2410 (Component Removal and Repair/Overhaul Record). The 2410 is ineffective as a comprehensive database due to inaccurate initial fault identification, restriction to single fault entry, and lack of enforcement in updating the actual fault-code at the rebuild

facilities. Microsoft Excel spreadsheets appear to be used as the primary means of organizing the information, however, the inherent flaws in data input to the system degrade the accuracy of such information.

To what extent are the metrics used to predict the loss of components in the future, and to what extent can new metrics be developed that would provide better insight to the problem and help avoid future life-cycle cost drivers? Currently, few if any metrics are used for prediction analysis. If the DA Form 2410 system were improved by using separate entries for QA personnel to enter subsequent findings and the rebuild facilities were required to enter a fault code without seeing the previous fault codes, it would be possible to far more accurately predict the true failure rates for these components.

What is the current annual cost of corrosion per AH-64 Apache airframe, and the overall cost to Army aviation, and what is the impact on readiness of losing these components to corrosion? The Depot maintenance cost of corrosion per airframe for gearbox replacement is $4,496. For all 748 airframes, the current annual charge is $3,363,637. The average annual cost for corrosion for organizational level maintenance is $74,469. The maintenance figures do not take into account the trouble-shooting and test flight requirements due to the exceptional variability of those requirements. However those costs could easily exceed the costs of the direct maintenance at the organizational

level. The readiness impact of losing these components is most evident by examining the status of gearbox availability. At the time of this thesis, the transmission stands at zero balance, and the tail-rotor gearbox has none for regular issue and only six available worldwide in war-reserve. Every aircraft that goes without a gearbox for one month uses 25% of its unscheduled maintenance hours. Implementing a program to overhaul these gearboxes with the new resin coating will: take an average of eight years; pay for itself by the end of the second year; and not cause any decrease in readiness at any time.

<u>What are the short-term and long-term costs and benefits of utilizing alternative procurement for the magnesium gearboxes?</u> The short-term cost of the program involves the first-year coating of gearboxes without any corresponding cost savings for that year. The average cost to implement the Rockhard process at the Depot for all gearboxes is $18,304 during the first year; and total implementation costs are $91,521. There are no long-term costs.

The long-term benefits are cost savings with NPVs of $56,012,033 for Depot contract costs, $1,563,858 in organizational maintenance, perhaps $2M or more in test flight and trouble-shooting costs, and an increase in readiness and safety that is difficult to accurately quantify.

<u>Are there procurement alternatives for those components on the AH-64 Apache which are highly-susceptible to corrosion that can lower</u>

life-cycle costs? The option explored in-depth was protecting the gearboxes with the new resin coating (Rockhard) known to be ten times more effective in corrosion resistance than what is in use today. Other options include using corrosion-prevention sprays and using aluminum in place of magnesium. However, a cursory cost-benefit analysis indicated they were significantly less cost-effective. A final option that should be explored is further refining our magnesium to reduce iron content and stabilize the material.

What responsibility does the PM have for funding upgrades to a fielded system, what, if any, is the source of the funding, and how would the funding of a retrofit affect an operational unit's Operations and Maintenance-Army (OMA) funds? Once a system is fielded, it generally transitions from the PEO to the AMC where the PM either transitions with the program or a new PM is appointed. Guidance from OSD on down continues to put the onus on the PM for controlling life-cycle costs and for working aggressively toward upgrading systems to lower system costs. PMs lack definitive information and visibility from which to base key cost-reduction issues. Struggles continue on issues including accountability of life-cycle costs, how the necessary upgrades are to be funded, what appropriation is to be used, and where those savings are realized. There are currently many unresolved issues that hinder the PM's ability to control all life-cycle costs.

B. CONCLUSION

Program Managers need an accurate database to capture life-cycle costs before they can possibly control those costs effectively. The cost reduction programs struggle to follow directives from the OSD, but remain unfunded as rules for program implementation and funding evolve on a regular basis. PMs struggle to find cost-saving initiatives, but assume funding risk in submitting those initiatives.

The magnesium used to make the AH-64 gearbox housings is not effectively coated to prevent corrosion. The cost of upgrading the coating to the best available protectant adds only a one to two percent increase in overhaul and production cost, but provides millions in potential cost savings. The saving to investment ratio is a compelling 629:1.

C. RECOMMENDATIONS

The Army must establish an accurate database to capture life-cycle costs for all high-dollar aviation components. Cost reduction programs must be funded adequately and provide clear, well-disseminated guidance to PMs. PMs need to be empowered to control all aspects of their program that drive life-cycle costs.

Corpus Christi Army Depot should immediately begin overhauling all magnesium gearboxes with the newest resin-based coating. All

procedures, personnel, and equipment are in place and the start-up costs are minimal. The progress of the program should be tracked and the cost-savings shared between the PM, AMC, and DA.

D. LIMITATIONS OF THE RESEARCH

Although most of the individuals contacted by phone and email responded reasonably well, the site visit was exponentially more valuable for gaining access to information which seemed to some individuals to be "close-hold." Additional visits to follow-up with the various points of contact would have been invaluable in gaining trust and gathering an even more complete understanding of all issues. Specific limitations for technical information are found in Chapter IV, section B.

E. AREAS FOR FURTHER RESEARCH

The Blackhawk PM gains invaluable corrosion prevention information from the Navy. Could the Apache PM benefit in reducing his life-cycle costs by forming a "teaming" relationship with the Blackhawk PM?

What systems engineering process allowed the development of a specification which failed to prevent gearbox corrosion?

Why has the specification never been updated and how many other out-dated Apache specifications are driving up life-cycle costs?

What changes are in effect for the Commanche that will prevent increased life-cycle costs on that airframe?

Could improved refinement of U.S. magnesium provide a significant increase in corrosion protection?

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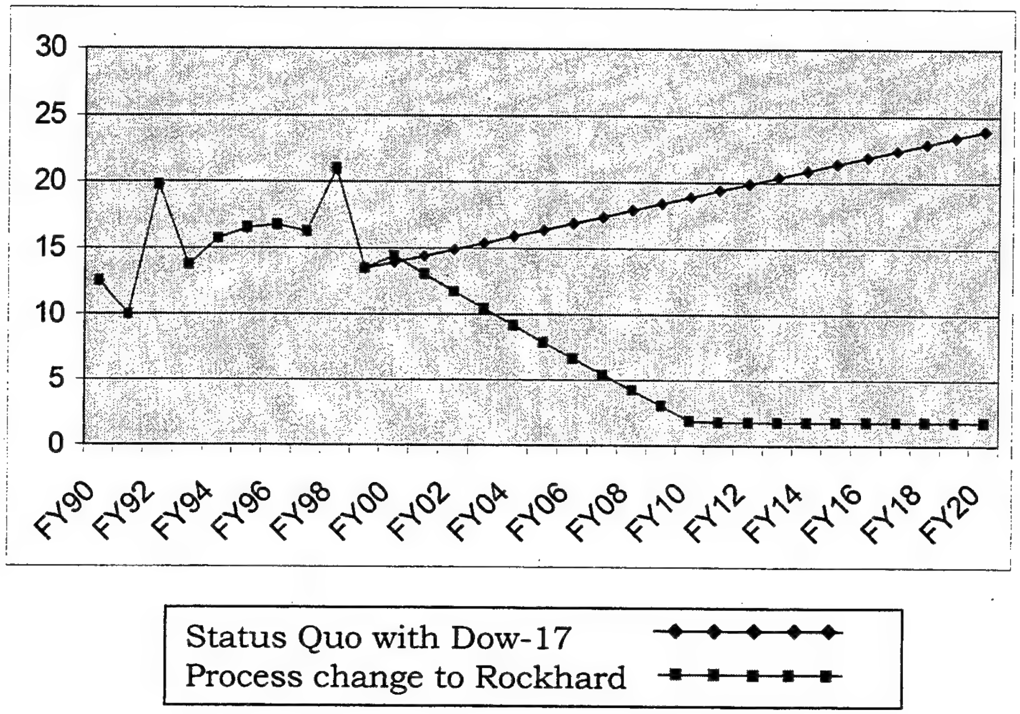
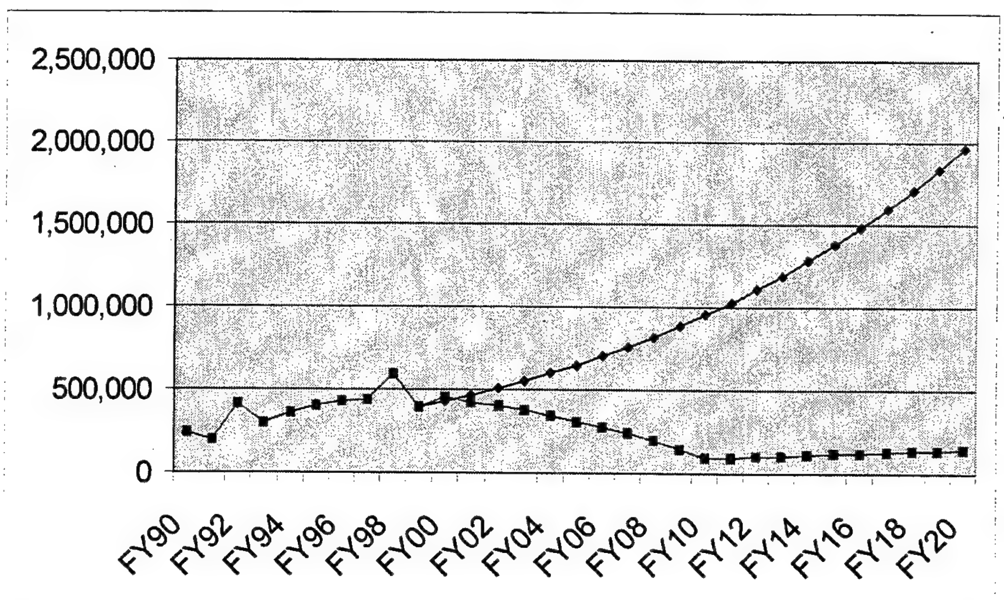
APPENDIX A. GEARBOX LIFE-CYCLE COMPARISON CHARTS

LEFT NOSE GEARBOX

LNG Failure rate comparison

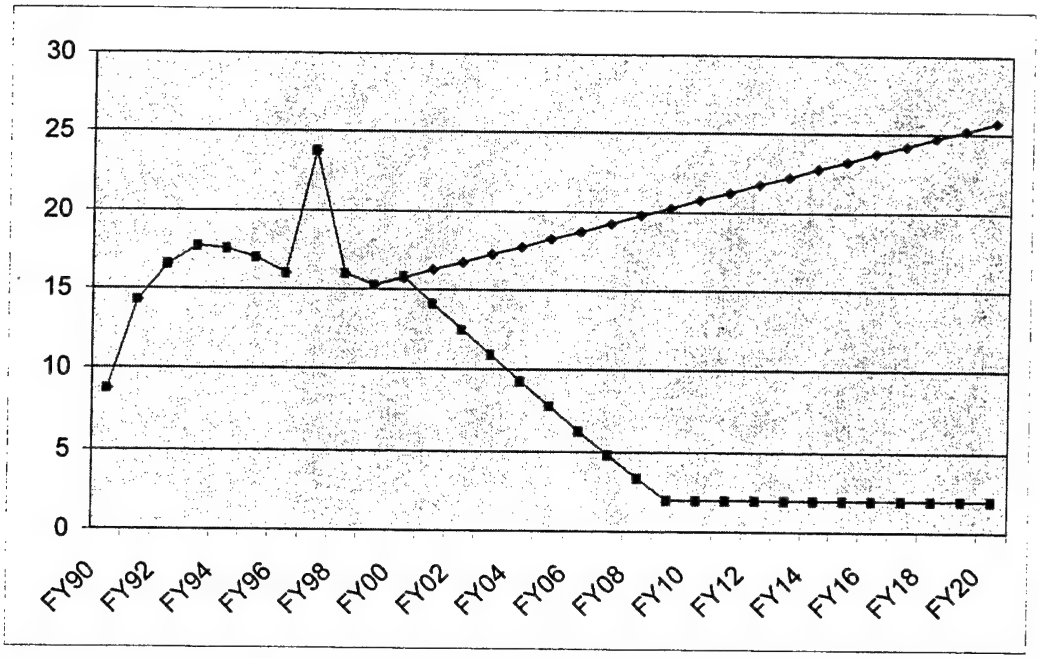


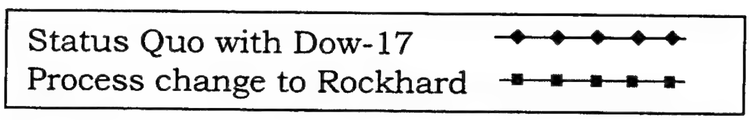
LNG Life-cycle cost comparison



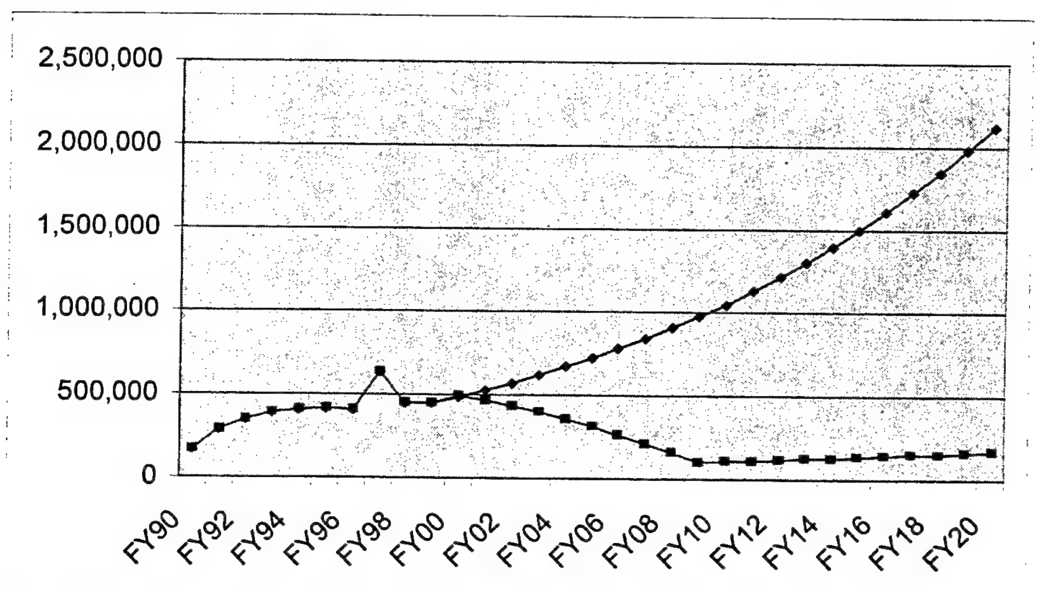
RIGHT NOSE GEARBOX

RNG Failure rate comparison



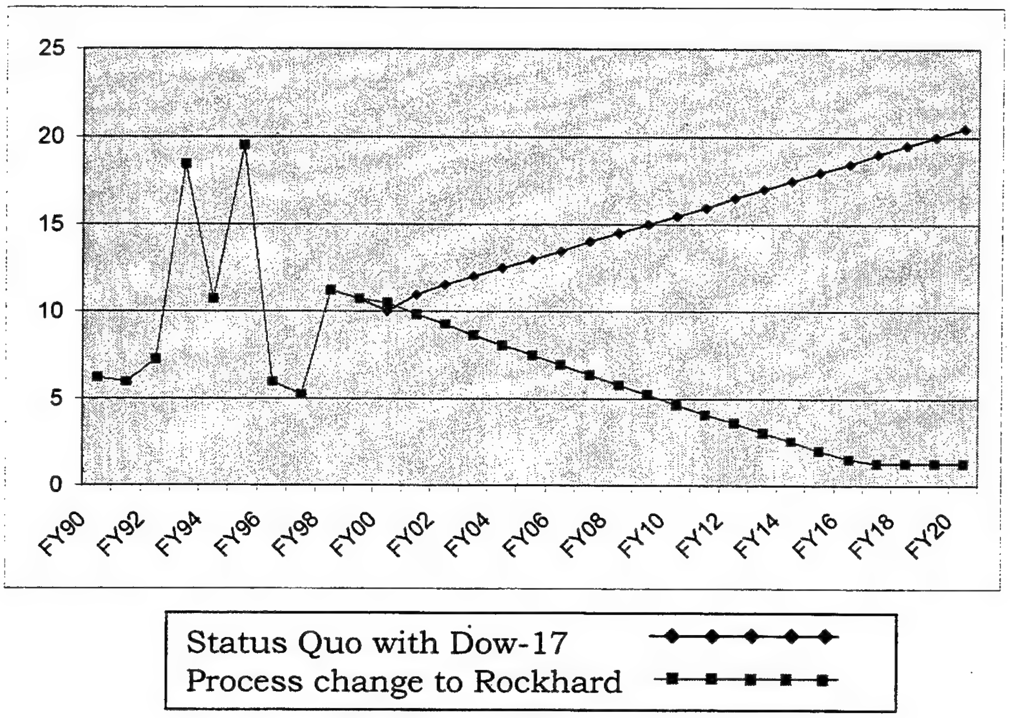


RNG Life-cycle cost comparison

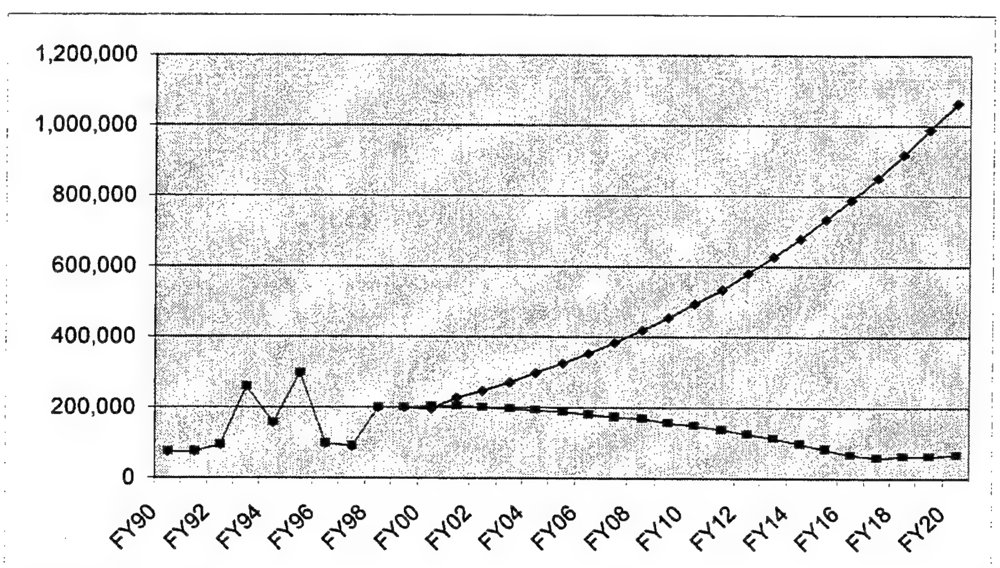


INTERMEDIATE GEARBOX

IGB Failure rate comparison

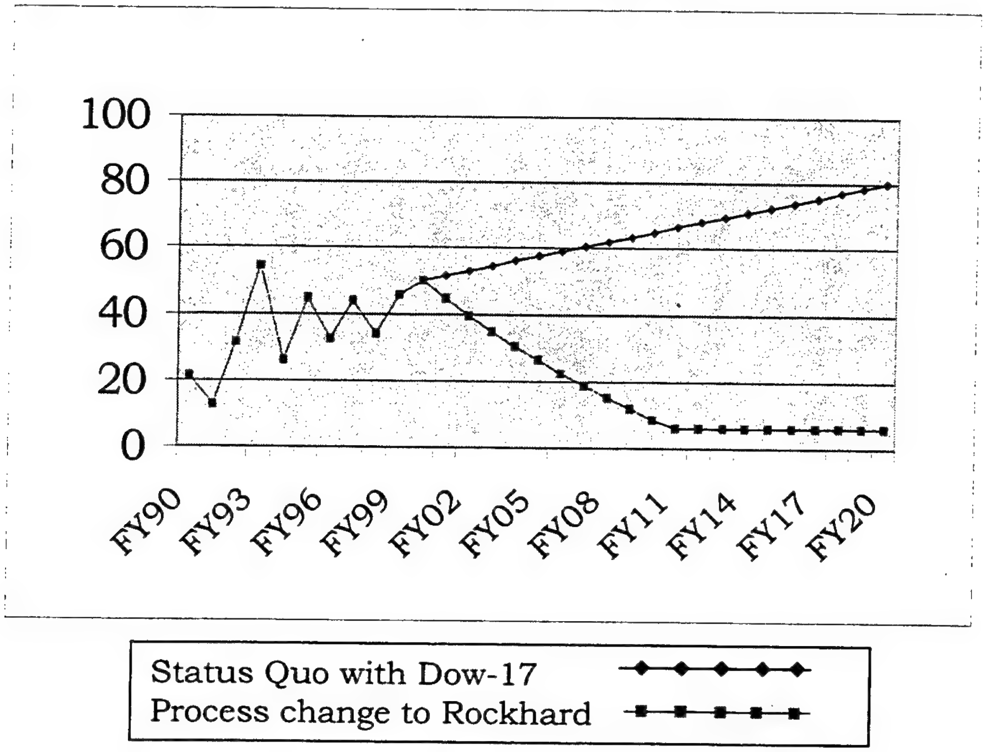


IGB Life-cycle cost comparison

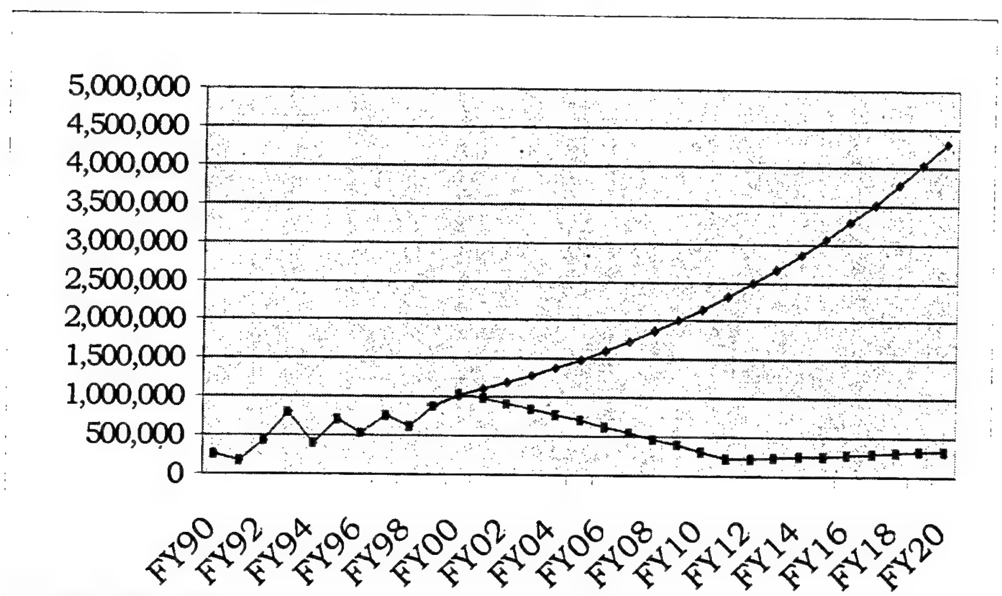


TAIL-ROTOR GEARBOX

TRGB Failure rate comparison

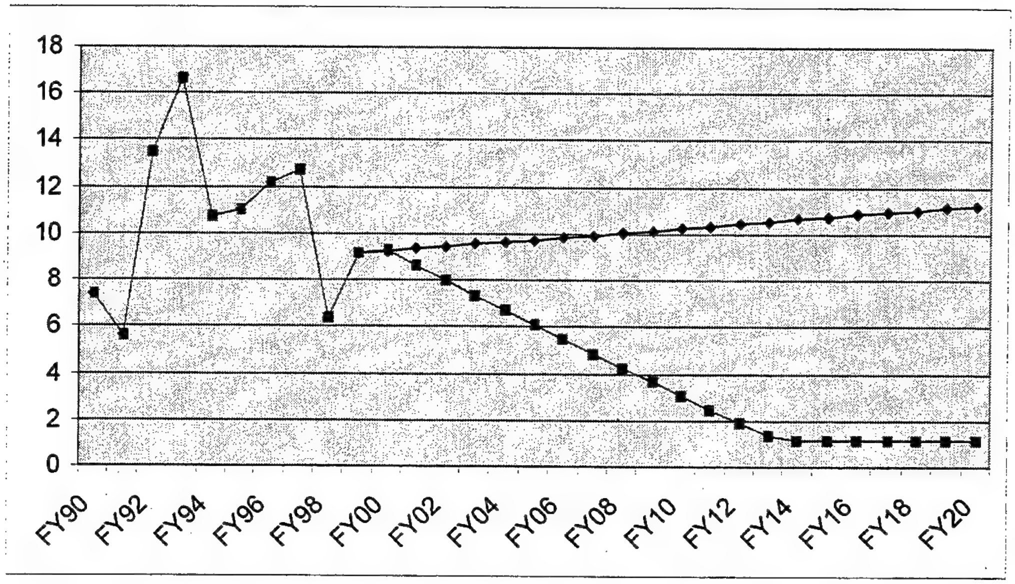


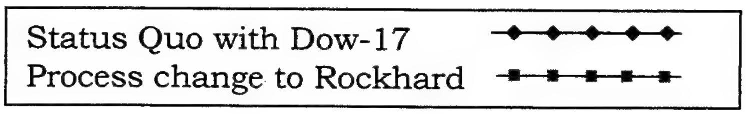
TRGB Life-cycle cost



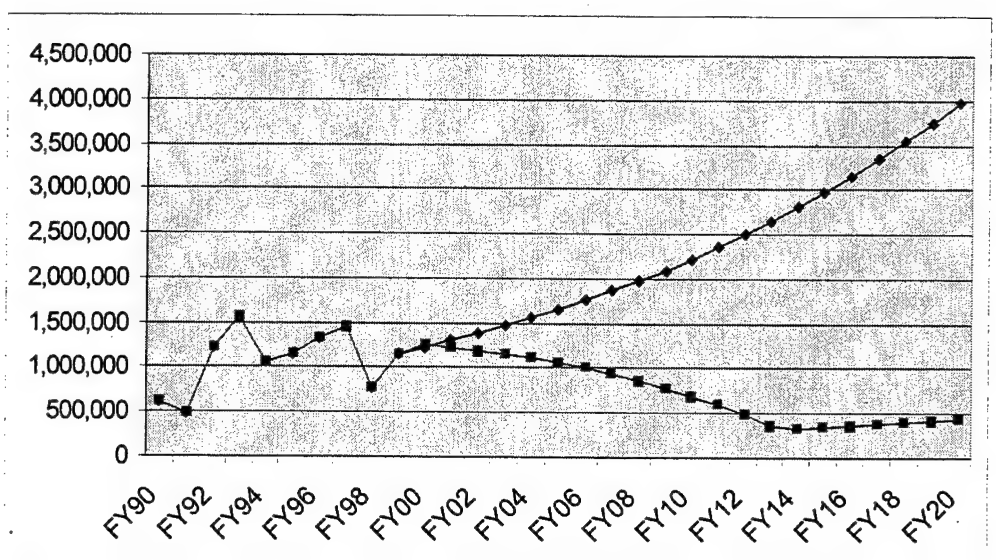
TRANSMISSIONS

XMSN Failure rate comparison





XMSN Life-cycle cost



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APPENDIX B. PRE-SHOP ANALYSIS TEAM LEDGER

Date	PCN	NOMEN	SEQ	OH	PSA	INSPECTION FINDINGS	CORROSION FOUND
1992	J01JPV	Tail Rotor	1	OH	BT	Crash Damage	
1992	J01JPV	Tail Rotor	2	OH	BT	Crash Damage	
1992	L01JPV	Tail Rotor	1	OH	BT	Accident Damage	
1993	L01JPV	Tail Rotor	1A	OH	BT	Leak	
1992	L01JPV	Tail Rotor	2	OH	BT	Leak	
1993	L01JPV	Tail Rotor	2A	OH	BT	F/C 070	
1993	L01JPV	Tail Rotor	3	OH	BT	QDR Exhibit	
1993	L01JPV	Tail Rotor	4	OH	BT	Loose Studs	
1993	L01JPV	Tail Rotor	5	OH	BT	Leak	
1993	L01JPV	Tail Rotor	6	OH	BT	Leak	
1993	L01JPV	Tail Rotor	7	OH	BT		corroded
1993	L01JPV	Tail Rotor	8	OH	BT	F/C 935	
1994	M01JPV	Tail Rotor	1	OH	R2H	dropped	corroded
1994	M01JPV	Tail Rotor	2	REP	GN	leak	
1994	M01JPV	Tail Rotor	3	REP	R2H	f/c 935 scarred	
	NONE		4				
1994	MO1JPV	Tail Rotor	5	OH	R2H	chips	
1994	MO1JPV	Tail Rotor	6	OH	R2H	bearing failure	
1994	MO1JPV	Tail Rotor	7	REP	GN	f/c sm1	
1994	MO1JPV	Tail Rotor	8	OH	R2H	lube low	corroded
1994	MO1JPV	Tail Rotor	9	OH	R2H	pinion dropped	corroded
1994	MO1JPV	Tail Rotor	10	OH	R2H	loose studs	corroded
1994	MO1JPV	Tail Rotor	11	OH	R2H	scuffed gears	
1994	MO1JPV	Tail Rotor	12	OH	R2H		corroded
1994	MO1JPV	Tail Rotor	13	REP	R2H	static scratches	
1994	MO1JPV	Tail Rotor	14	OH	GN		
1994	MO1JPV	Tail Rotor	15	OH	R2H	scuffed gears	
1994	MO1JPV	Tail Rotor	16	OH	R2H	overheated	
1994	MO1JPV	Tail Rotor	17	REP	R2H	leak	
1994	MO1JPV	Tail Rotor	18	OH	R2H	leak	corroded
1994	NONE		19				
1994	NONE		20				
1994	MO1JPV	Tail Rotor	21	OH	R2H		corroded
1994	NONE		22				
1994	MO1JPV	Tail Rotor	23	REP	R2H	leak	
1994	MO1JPV	Tail Rotor	24	REP	R2H	grooved	
1994	MO1JPV	Tail Rotor	25	REP	R2H		corroded
1994	MO1JPV	Tail Rotor	26	OH	R2H		corroded
1994	NONE		27				
1994	MO1JPV	Tail Rotor	28	OH	R2H		corroded
1994	MO1JPV	Tail Rotor	29	REP	GN	leak	
1994	MO1JPV	Tail Rotor	30	OH	R2H	elongated studs	corroded
1994	MO1JPV	Tail Rotor	31	OH	R2H		corroded
1994	MO1JPV	Tail Rotor	32	OH	R2H	overheated & leak	
1994	MO1JPV	Tail Rotor	33	REP	R2H		corroded
1994	MO1JPV	Tail Rotor	34	OH	R2H		corroded
1994	MO1JPV	Tail Rotor	35	OH	GN	scuffed	corroded
1994	MO1JPV	Tail Rotor	36	OH	R2H	overheating	
1994	MO1JPV	Tail Rotor	37	REP	GN	leak	
1994	MO1JPV	Tail Rotor	38	OH	GN	overheated	
1994	MO1JPV	Tail Rotor	39	REP	R2H	leak	
1994	MO1JPV	Tail Rotor	40	REP	GN	leak	

Date	PCN	NOMEN	SEQ	OH	PSA	INSPECTION FINDINGS	CORROSION FOUND
1994	MO1JPV	Tail Rotor	68	REP	GN		
1994	MO1JPV	Tail Rotor	69	OH	GN		
1995	MO1JPV	Tail Rotor	70	OH	R2H	scuffed gears	corroded
1995	MO1JPV	Tail Rotor	71	OH	GN		corroded
1995	MO1JPV	Tail Rotor	72	OH	GN		corroded
1995	MO1JPV	Tail Rotor	73	OH	R2H		corroded
1995	MO1JPV	Tail Rotor	74	OH	GN	leak	
1995	MO1JPV	Tail Rotor	75	OH	R2H		corroded
1995	MO1JPV	Tail Rotor	76	REP	GN	leak	
1995	MO1JPV	Tail Rotor	77	OH	GN		corroded
1995	MO1JPV	Tail Rotor	78	OH	GN	Over temp	
1995	MO1JPV	Tail Rotor	79	OH	GN	crash damage	
1995	MO1JPV	Tail Rotor	80	OH	GN		corroded
1995	MO1JPV	Tail Rotor	81	OH	GN		corroded
1995	MO1JPV	Tail Rotor	82	OH	GN		corroded
1995	MO1JPV	Tail Rotor	83	REP	GN	leak	
1995	MO1JPV	Tail Rotor	84	OH	GN	previously disassembly	
1995	MO1JPV	Tail Rotor	85	OH	R2H		corroded
1995	MO1JPV	Tail Rotor	86	OH	GN	previously disassembly	
1995	MO1JPV	Tail Rotor	87	REP	R2H	leak	
1995	MO1JPV	Tail Rotor	87A	OH	R2H		corroded
1995	MO1JPV	Tail Rotor	88	REP	R2H		corroded
1995	MO1JPV	Tail Rotor	89	OH	R2H	pinion dropped	corroded
1995	MO1JPV	Tail Rotor	90	REP	R2H		corroded
1995	MO1JPV	Tail Rotor	91	OH	GN	damaged studs	corroded
1995	MO1JPV	Tail Rotor	92	OH	R2H	overheated	
1995	MO1JPV	Tail Rotor	93	OH	GN	structural failure	
1995	MO1JPV	Tail Rotor	94	OH	R2H		corroded
1995	MO1JPV	Tail Rotor	95	OH	R2H	broken studs	
1995	MO1JPV	Tail Rotor	96	OH	R2H	no defect found	
1995	MO1JPV	Tail Rotor	97	OH	R2H		corroded
1995	MO1JPV	Tail Rotor	98	OH	R2H	loose studs	
1995	MO1JPV	Tail Rotor	99	OH	R2H		corroded
1995	MO1JPV	Tail Rotor	100	OH	GN		corroded
1995	NO1JPV	Tail Rotor	1	OH	R2H	scuffed	
1995	NO1JPV	Tail Rotor	2	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	3	OH	R2H	leak	
1995	NO1JPV	Tail Rotor	3A	OH	GN		corroded
1995	NO1JPV	Tail Rotor	4	OH	R2H	leak	
1995	NO1JPV	Tail Rotor	4A	OH	GN	leak	
1995	NO1JPV	Tail Rotor	4B	OH	GN	static scratched	
1995	NO1JPV	Tail Rotor	5	OH	GN	poor records	corroded
1995	NO1JPV	Tail Rotor	6	OH	GN	leak	corroded
1995	NO1JPV	Tail Rotor	7	OH	R2H	leak	
1995	NO1JPV	Tail Rotor	8	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	9	OH	R2H	overheats	
1995	NO1JPV	Tail Rotor	10	OH	GN	poor records	
1995	NO1JPV	Tail Rotor	11	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	12	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	13	OH	GN		corroded
1995	NO1JPV	Tail Rotor	14	OH	GN		corroded
1995	NO1JPV	Tail Rotor	15	OH	GN	leak	

Date	PCN	NOMEN	SEQ	OH	PSA	INSPECTION FINDINGS	CORROSION FOUND
1995	NO1JPV	Tail Rotor	16	OH	GN	leak	corroded
1995	NO1JPV	Tail Rotor	17	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	18	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	19	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	19A	REP	R2H	NEOF	
1995	NO1JPV	Tail Rotor	20	OH	R2H	leak, contaminated	
1995	NO1JPV	Tail Rotor	20A	REP	R2H	static scratched	
1995	NO1JPV	Tail Rotor	21	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	22	REP	GN	nicked pinion gear	
1995	NO1JPV	Tail Rotor	23	REP	GN	leak	
1995	NO1JPV	Tail Rotor	24	OH	R2H	lightning strike	
1995	NO1JPV	Tail Rotor	25	OH	GN	leak, partly disassembly	
1995	NO1JPV	Tail Rotor	26	OH	R2H	galled out, contaminated	
1995	NO1JPV	Tail Rotor	27	OH	R2H	low grease	corroded
1995	NO1JPV	Tail Rotor	28	OH	R2H	scratched	corroded
1995	NO1JPV	Tail Rotor	29	OH	R2H	scratched	corroded
1995	NO1JPV	Tail Rotor	30	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	31	OH	R2H	overheated	
1995	NO1JPV	Tail Rotor	32	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	33	OH	R2H	grooved	corroded
1995	NO1JPV	Tail Rotor	34	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	35	REP	R2H	NEOF	
1995	NO1JPV	Tail Rotor	36	OH	R2H	accident damage	corroded
1995	NO1JPV	Tail Rotor	37	OH	R2H	no failure info	
1995	NO1JPV	Tail Rotor	38	OH	R2H	vibrations	corroded
1995	NO1JPV	Tail Rotor	39	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	40	OH	R2H/GN	leak	
1995	NO1JPV	Tail Rotor	41	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	42	OH	R2H	loose studs	corroded
1995	NO1JPV	Tail Rotor	43	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	44	OH	R2H	broken fin	corroded
1995	NO1JPV	Tail Rotor	45	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	46	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	47	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	48	OH	R2H	leak	
1995	NO1JPV	Tail Rotor	49	OH	R2H	contaminated	corroded
1995	NO1JPV	Tail Rotor	50	OH	GN		corroded
1995	NO1JPV	Tail Rotor	51	OH	R2H	dropped bad paint	
1995	NO1JPV	Tail Rotor	52	OH	R2H	fc not reliable	
1995	NO1JPV	Tail Rotor	53	OH	R2H	leak	
1995	NO1JPV	Tail Rotor	54	OH	GN	leak	corroded
1995	NO1JPV	Tail Rotor	55	OH	GN	leak	corroded
1995	NO1JPV	Tail Rotor	56	OH	GN	leak	corroded
1995	NO1JPV	Tail Rotor	57	OH	GN	leak, scuffed gears	
1995	NO1JPV	Tail Rotor	58	OH	GN	leak	corroded
1995	NO1JPV	Tail Rotor	59	OH	GN	leak	corroded
1995	NO1JPV	Tail Rotor	60	OH	GN		corroded
1995	NO1JPV	Tail Rotor	61	OH	R2H	leak	corroded
1995	NO1JPV	Tail Rotor	62	OH	R2H	scuffed gears	corroded
1995	NO1JPV	Tail Rotor	63	OH	GN		corroded
1995	NO1JPV	Tail Rotor	64	OH	GN	overheated	
1995	NO1JPV	Tail Rotor	65	OH	GN	leak	
1995	NO1JPV	Tail Rotor	66	OH	GN		corroded
1995	NO1JPV	Tail Rotor	67	OH	R2H		corroded

Date	PCN	NOMEN	SEQ	OH	PSA	INSPECTION FINDINGS	CORROSION FOUND
1995	NO1JPV	Tail Rotor	68	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	69	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	70	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	71	OH	R2H	poor records	corroded
1995	NO1JPV	Tail Rotor	72	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	73	REP	R2H		corroded
1995	NO1JPV	Tail Rotor	74	OH	R2H	lightning strike	
1995	NO1JPV	Tail Rotor	75	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	76	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	77	OH	R2H	scuffed gears	
1995	NO1JPV	Tail Rotor	78	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	79	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	80	OH	R2H	scuffed gears	
1995	NO1JPV	Tail Rotor	81	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	82	OH	R2H	overheated	
1995	NO1JPV	Tail Rotor	83	OH	R2H	dropped	
1995	NO1JPV	Tail Rotor	84	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	85	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	86	REP	R2H		corroded
	NONE		87				
1995	NO1JPV	Tail Rotor	88	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	89	OH	R2H		corroded
1995	NO1JPV	Tail Rotor	90	REP	R2H	leak	
1995	NO1JPV	Tail Rotor	91	REP	R2H	grooved fc214	
1996	NO1JPV	Tail Rotor	92	OH	R2H	overheated	
1996	NO1JPV	Tail Rotor	93	OH	R2H	overheated	
1996	NO1JPV	Tail Rotor	94	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	95	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	96	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	97	OH	R2H	broken fin	corroded
1996	NO1JPV	Tail Rotor	98	OH	R2H		corroded
1996	NO1JPV	Tail Rotor					
1996	NO1JPV	Tail Rotor					
1996	NO1JPV	Tail Rotor					
1996	PO1JPV	Tail Rotor	1	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	2	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	3	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	4	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	5	OH	R2H	bad records	
1996	PO1JPV	Tail Rotor	6	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	7	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	8	OH	R2H	lightning strike	
1996	PO1JPV	Tail Rotor	9	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	10	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	11	REP	R2H	leak	
1996	PO1JPV	Tail Rotor	12	REP	R2H	leak	
1996	PO1JPV	Tail Rotor	13	REP	R2H	gouge	
1996	PO1JPV	Tail Rotor	14	OH	R2H	leak	corroded
1996	PO1JPV	Tail Rotor	15	OH	R2H	leak	corroded
1996	PO1JPV	Tail Rotor	16	REP	R2H	NEOF	
1996	PO1JPV	Tail Rotor	17	OH	R2H	contaminated	corroded
1996	PO1JPV	Tail Rotor	18	OH	R2H	contaminated	
1996	PO1JPV	Tail Rotor	18A	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	19	OH	R2H		corroded
1996	PO1JPV	Tail Rotor	20	FMS			

Date	PCN	NOMEN	SEQ	OH	PSA	INSPECTION FINDINGS	CORROSION FOUND
1996	NO1JPV	Tail Rotor	21	OH	R2H	QDR investigation	
1996	NO1JPV	Tail Rotor	22	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	23	BER	R2H	severe corrosion	corroded
1996	NO1JPV	Tail Rotor	24	OH	R2H		corroded
	NONE		25				
1996	NO1JPV	Tail Rotor	26	OH	R2H	quill dropped	corroded
1996	NO1JPV	Tail Rotor	26A	BER	R2H	crash damage	
1996	NO1JPV	Tail Rotor	27	OH	R2H	crash damage	
1996	NO1JPV	Tail Rotor	28	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	29	OH	R2H	scuffed gears	corroded
1996	NO1JPV	Tail Rotor	30	OH	R2H	no failure code	
1996	NO1JPV	Tail Rotor	31	REP	R2H	leak	
1996	NO1JPV	Tail Rotor	32	OH	R2H	70% corroded	corroded
1996	NO1JPV	Tail Rotor	33	OH	R2H	pinion fell out, contaminated	
1996	NO1JPV	Tail Rotor	34	OH	R2H	poor condition	
1996	NO1JPV	Tail Rotor	35	REP	R2H	leak	
1996	NO1JPV	Tail Rotor	36	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	37	OH	R2H	lightning strike	corroded
1996	NO1JPV	Tail Rotor	38	OH	R2H	leak, abused	
1996	NO1JPV	Tail Rotor	39	REP	R2H	leak	
1996	NO1JPV	Tail Rotor	40	OH	R2H	leak	corroded
	NONE		41				
1996	NO1JPV	Tail Rotor	42	OH	R2H	bearing failure	
1996	NO1JPV	Tail Rotor	42A	REP	R2H	input sleeve not modified	
1996	NO1JPV	Tail Rotor	43	OH	R2H	lightning strike	
1996	NO1JPV	Tail Rotor	44	REP	R2H	leak	
1996	NO1JPV	Tail Rotor	45	OH	R2H	overheated	
1996	NO1JPV	Tail Rotor	46	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	47	OH	R2H	sudden stop	
	NONE		48				
1996	NO1JPV	Tail Rotor	49	OH	R2H	leak	corroded
1996	NO1JPV	Tail Rotor	50	OH	R2H	static gouged	corroded
1996	NO1JPV	Tail Rotor	51	OH	R2H	overheated	
1996	NO1JPV	Tail Rotor	52	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	53	OH	R2H	crash damage	
1996	NO1JPV	Tail Rotor	54	OH	R2H		corroded
	NONE		55				
1996	NO1JPV	Tail Rotor	56	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	56A	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	57	OH	R2H	Over speed	
1996	NO1JPV	Tail Rotor	58	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	59	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	60	OH	R2H	overheated	
1996	NO1JPV	Tail Rotor	61	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	62	REP	R2H	leak	
1996	NO1JPV	Tail Rotor	63	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	64	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	65	OH	R2H		corroded
1996	NO1JPV	Tail Rotor	66	OH	R2H	A1B investigation	
1996	NO1JPV	Tail Rotor	67	OH	R2H	poor condition	
1996	NO1JPV	Tail Rotor	68	REP	R2H	suspected overheating	
	NONE		69				
1996	NO1JPV	Tail Rotor	70	REP	R2H	leak	
1996	NO1JPV	Tail Rotor	71	OH	R2H	tampered with	corroded
1996	NO1JPV	Tail Rotor	72	OH	R2H	poor condition	

Date	PCN	NOMEN	SEQ	OH	PSA	INSPECTION FINDINGS	CORROSION FOUND
1996	Q01JPV	Tail Rotor	1	OH	R2H	low grease	corroded
1996	Q01JPV	Tail Rotor	2	REP	R2H		corroded
1996	Q01JPV	Tail Rotor	3	OH	R2H		corroded
1996	Q01JPV	Tail Rotor	4	OH	R2H		corroded
1996	Q01JPV	Tail Rotor	5	OH	R2H	A1B investigation	corroded
1996	Q01JPV	Tail Rotor	6	OH	R2H		corroded
1996	Q01JPV	Tail Rotor	7	OH	R2H		corroded
1996	Q01JPV	Tail Rotor	8	OH	R2H	A1B investigation	corroded
1996	Q01JPV	Tail Rotor	9	OH	R2H	lightning strike	
1996	Q01JPV	Tail Rotor	10	OH	R2H	leak	corroded
	NONE		11				
	NONE		down				
	NONE		to 23				
	NONE		none				
1997	Q01JPV	Tail Rotor	24	REP	R2H		corroded
1997	Q01JPV	Tail Rotor	25	OH	R2H		corroded
1997	Q01JPV	Tail Rotor	26	REP	R2H	leak, t50H 04	
1997	Q01JPV	Tail Rotor	27	OH	R2H		corroded
1997	Q01JPV	Tail Rotor	28	OH	R2H	metal chunks inside	
1997	Q01JPV	Tail Rotor	29	OH	R2H		corroded
1997	Q01JPV	Tail Rotor	30	OH	R2H		corroded
1997	Q01JPV	Tail Rotor	31	OH	R2H		corroded
1997	Q01JPV	Tail Rotor	32	REP	R2H	fcsc1	corroded
1997	Q01JPV	Tail Rotor	33	REP	R2H	leak	
1997	Q01JPV	Tail Rotor	34	OH	R2H		corroded
1997	Q01JPV	Tail Rotor	35	OH	R2H		corroded
1997	Q01JPV	Tail Rotor	36	OH	R2H		corroded
1997	QO1JPV	Tail Rotor	37	REP	R2H	vibration not confirmed	
1997	QO1JPV	Tail Rotor	38	REP	R2H	leak	
1997	QO1JPV	Tail Rotor	39	REP	R2H	possibly stud misalignment	
1997	QO1JPV	Tail Rotor	40	OH	R2H	bad failure code	
1997	QO1JPV	Tail Rotor	40A	OH	R2H		corroded
1997	QO1JPV	Tail Rotor	41	REP	R2H	leak	
1997	QO1JPV	Tail Rotor	42	REP	R2H	leak	
1997	QO1JPV	Tail Rotor	43	OH	R2H		corroded
1997	QO1JPV	Tail Rotor	44	REP	R2H	leak	
1997	QO1JPV	Tail Rotor	45	OH	R2H	bent stud	corroded
1997	QO1JPV	Tail Rotor	46	OH	R2H	chips	
1997	QO1JPV	Tail Rotor	47	REP	R2H	TSOH	corroded
1997	QO1JPV	Tail Rotor	48	OH	R2H	overheats	
1997	QO1JPV	Tail Rotor	49	OH	R2H	overheated	
1997	QO1JPV	Tail Rotor	50	REP	R2H	TSOH 0	corroded
1997	RO1JPV	Tail Rotor	1	OH	GN		corroded
1997	RO1JPV	Tail Rotor	2	REP	R2H		corroded
1997	RO1JPV	Tail Rotor	3	OH	R2H		corroded
1997	RO1JPV	Tail Rotor	4	BER	GN		corroded
1997	RO1JPV	Tail Rotor	5	REP	R2H	leak	
1997	RO1JPV	Tail Rotor	6	REP	GN	evidence contamination	
1997	RO1JPV	Tail Rotor	7	REP	GN	TSOH 311	
1997	RO1JPV	Tail Rotor	8	OH	R2H	overheated	
1997	RO1JPV	Tail Rotor	9	REP	R2H	TSOH 0, damaged studs	
1997	RO1JPV	Tail Rotor	10	REP	R2H	leak	
1998	RO1JPV	Tail Rotor	11	OH	R2H	No failure info	

Date	PCN	NOMEN	SEQ	OH	PSA	INSPECTION FINDINGS	CORROSION FOUND
1998	RO1JPV	Tail Rotor	12	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	13	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	14	OH	R2H	leak	corroded
1998	RO1JPV	Tail Rotor	15	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	16	REP	R2H	pinion dropped	
1998	RO1JPV	Tail Rotor	17	OH	R2H	scuffed gears	
1998	RO1JPV	Tail Rotor	18	REP	R2H	pinion dropped	
1998	RO1JPV	Tail Rotor	19	OH	R2H	poor condition	
1998	RO1JPV	Tail Rotor	20	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	21	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	22	OH	R2H	leak, overheated	corroded
1998	RO1JPV	Tail Rotor	23	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	24	REP	R2H	scratched static	
1998	RO1JPV	Tail Rotor	25	OH	R2H	overheated	
1998	RO1JPV	Tail Rotor	26	REP	R2H	leak	
1998	RO1JPV	Tail Rotor	27	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	28	OH	R2H	A1B Investigation	corroded
1998	RO1JPV	Tail Rotor	29	OH	R2H	vibration	corroded
1998	RO1JPV	Tail Rotor	30	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	31	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	32	REP	R2H	leak	
1998	RO1JPV	Tail Rotor	33	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	34	OH	R2H	leak	corroded
1998	RO1JPV	Tail Rotor	35	REP	R2H	leak	
1998	RO1JPV	Tail Rotor	36	OH	R2H		corroded
1998	RO1JPV	Tail Rotor	37	OH	R2H	bearing failure	
1998	RO1JPV	Tail Rotor	38	REP	R2H	leak	
1998	R01JPV	Tail Rotor	39	OH	R2H	overheated	
1998	R01JPV	Tail Rotor	40	OH	R2H	vibration, disassembled	
1998	R01JPV	Tail Rotor	41	OH	R2H	studs	corroded
1998	R01JPV	Tail Rotor	42	OH	R2H		corroded
1998	R01JPV	Tail Rotor	43	OH	R2H		corroded
1998	R01JPV	Tail Rotor	44	OH	R2H	leak, scuffed gears	
1998	R01JPV	Tail Rotor	45	OH	R2H	leak	corroded
1998	R01JPV	Tail Rotor	46	OH	R2H	leak	corroded
1998	R01JPV	Tail Rotor	47	OH	R2H		corroded
1998	R01JPV	Tail Rotor	48	OH	R2H	crash damage	
1998	R01JPV	Tail Rotor	49	OH	R2H		corroded
1998	R01JPV	Tail Rotor	50	OH	R2H	scuffed gears	corroded
1998	R01JPV	Tail Rotor	51	OH	R2H	studs (SOF)	corroded
1998	R01JPV	Tail Rotor	52	OH	R2H	leak	corroded
1998	R01JPV	Tail Rotor	53	OH	R2H		corroded
1998	R01JPV	Tail Rotor	54	OH	R2H		corroded
1998	R01JPV	Tail Rotor	55	OH	R2H	leak	corroded
1998	R01JPV	Tail Rotor	56	OH	R2H		corroded
1998	R01JPV	Tail Rotor	57	REP	R2H	(SOF) misalign studs	
1998	R01JPV	Tail Rotor	58	OH	R2H	leak	corroded
1998	R01JPV	Tail Rotor	59	OH	R2H		corroded
1998	R01JPV	Tail Rotor	60	REP	R2H	leak	
1998	R01JPV	Tail Rotor	61	OH	R2H		corroded
1999	S01JPV	Tail Rotor	31	OH	R2H	cracked mount	corroded
1999	S01JPV	Tail Rotor	32	OH	R2H	overheated	
1999	S01JPV	Tail Rotor	33	REP	R2H	output shaft stripped threads	
1999	S01JPV	Tail Rotor	34	REP	R2H	static gouged	

Date	PCN	NOMEN	SEQ	OH	PSA	INSPECTION FINDINGS	CORROSION FOUND
1999	S01JPV	Tail Rotor	35	OH	R2H	scuffed gears	
1999	S01JPV	Tail Rotor	36	OH	R2H	contaminated	corroded
1999	S01JPV	Tail Rotor	37	REP	R2H		corroded
1999	S01JPV	Tail Rotor	38	REP	R2H	leak	
1999	S01JPV	Tail Rotor	39	REP	R2H	leak	corroded
1999	S01JPV	Tail Rotor	40	OH	R2H	leak	corroded
1999	S01JPV	Tail Rotor	41	OH	R2H	leak	corroded
1999	S01JPV	Tail Rotor	42	REP	R2H	leak	
1999	S01JPV	Tail Rotor	43	REP	R2H	leak	
1999	S01JPV	Tail Rotor	44	OH	R2H	sleeve mod	corroded
1999	S01JPV	Tail Rotor	45	OH	R2H	leak	corroded
1999	S01JPV	Tail Rotor	46	OH	R2H		corroded
1999	S01JPV	Tail Rotor	47	REP	R2H	bent studs TSOH 0	
1999	S01JPV	Tail Rotor	48	OH	R2H	scuffed gears, leak	corroded
1999	S01JPV	Tail Rotor	49	REP	R2H	leak TSOH 46	
1999	S01JPV	Tail Rotor	50	OH	R2H	leak	corroded
1999	T01JPV	Tail Rotor	1	OH	R2H	leak, bad gear patterns	
1999	T01JPV	Tail Rotor	2	OH	R2H		corroded
1999	T01JPV	Tail Rotor	3	REP	R2H	fc 020	
1999	T01JPV	Tail Rotor	4	REP	R2H	leak	
1999	T01JPV	Tail Rotor	5	REP	R2H	leak	
1999	T01JPV	Tail Rotor	6	REP	R2H	leak	
1999	T01JPV	Tail Rotor	7	REP	R2H	leak	
1999	T01JPV	Tail Rotor	8	OH	R2H	leak	corroded
1999	T01JPV	Tail Rotor	9	OH	R2H	leak	corroded
1999	T01JPV	Tail Rotor	10	OH	R2H	scuffed gears, leak	

Description of entries in PSA Logbook	
JPV (JO1, etc.)	Code for Tail Rotor Gearbox (Batch number)
PCN	Production Control Number (funding determination)
NOMEN	Nomenclature of part
SEQ	Sequence (order they are to be repaired)
PSA	Pre Shop Analysis – Individual doing inspection

APPENDIX C. PIVOT TABLE RESULTS

Faults other than Corrosion	Corroded vs. Not Corroded Data	Corroded	(Blank)	Grand total	Correlation of Faults
SOF misalign stud	Count of Corroded				
	Count of Not corroded		1	1	
70% corroded	Count of Corroded	1		1	
	Count of Not corroded	1		1	
A1B investigation	Count of Corroded	3		3	
	Count of Not corroded	3	1	4	75%
accident	Count of Corroded				
	Count of Not corroded		1	1	
Accident Damage	Count of Corroded	1		1	
	Count of Not corroded	1	1	2	50%
bad failure code	Count of Corroded				
	Count of Not corroded		1	1	
bad records	Count of Corroded				
	Count of Not corroded		1	1	
bearing failure	Count of Corroded				
	Count of Not corroded		3	3	
bent stud	Count of Corroded	1		1	
	Count of Not corroded	1		1	
bent studs TSOH 0	Count of Corroded				
	Count of Not corroded		1	1	
broken fin	Count of Corroded	2		2	
	Count of Not corroded	2		2	
broken studs	Count of Corroded				
	Count of Not corroded		1	1	
chips	Count of Corroded				
	Count of Not corroded		2	2	
contaminated	Count of Corroded	5		5	
	Count of Not corroded	5	1	6	83%
cracked case	Count of Corroded				
	Count of Not corroded		1	1	
cracked mount	Count of Corroded	1		1	
	Count of Not corroded	1		1	
Crash Damage	Count of Corroded				
	Count of Not corroded		7	7	
damaged studs	Count of Corroded	1		1	
	Count of Not corroded	1		1	
dropped	Count of Corroded	1		1	

	Count of Not corroded	1	1	2	
dropped bad paint	Count of Corroded				
	Count of Not corroded		1	1	
elongated studs	Count of Corroded	1		1	
	Count of Not corroded	1		1	
contamination	Count of Corroded				
	Count of Not corroded		1	1	
F/C 070	Count of Corroded				
	Count of Not corroded		1	1	
F/C 935	Count of Corroded				
	Count of Not corroded		1	1	
f/c 935 scarred	Count of Corroded				
	Count of Not corroded		1	1	
f/c sm1	Count of Corroded				
	Count of Not corroded		1	1	
fc 020	Count of Corroded				
	Count of Not corroded		1	1	
fc not reliable	Count of Corroded				
	Count of Not corroded		1	1	
fcsc1	Count of Corroded	1		1	
	Count of Not corroded	1		1	
gouge	Count of Corroded				
	Count of Not corroded		1	1	
grooved	Count of Corroded	1		1	
	Count of Not corroded	1	1	2	50%
grooved fc214	Count of Corroded				
	Count of Not corroded		1	1	
guiled out,	Count of Corroded				
	Count of Not corroded		1	1	
input sleeve not moded	Count of Corroded				
	Count of Not corroded		1	1	
Leak	Count of Corroded	39		39	
	Count of Not corroded	39	64	103	38%
leak	Count of Corroded				
	Count of Not corroded		1	1	
leak TSOH 46	Count of Corroded				
	Count of Not corroded		1	1	
leak, abused	Count of Corroded				
	Count of Not corroded		1	1	
leak, bad gear	Count of Corroded				
	Count of Not corroded		1	1	
leak, contaminated	Count of Corroded				

	Count of Not corroded		1	1
leak, overheated	Count of Corroded	1		1
	Count of Not corroded	1		1
leak, partly dissy	Count of Corroded			
	Count of Not corroded		1	1
leak, scuffed gears	Count of Corroded			
	Count of Not corroded		2	2
leak, t50H 04	Count of Corroded			
	Count of Not corroded		1	1
lightning strike	Count of Corroded	1		1
	Count of Not corroded	1	5	6	17%
lightning strike	Count of Corroded			
	Count of Not corroded		1	1
Loose Studs	Count of Corroded	2		2
	Count of Not corroded	2	2	4	50%
low grease	Count of Corroded	2		2
	Count of Not corroded	2		2	100%
lube low	Count of Corroded	1		1
	Count of Not corroded	1		1
metal pieces inside	Count of Corroded			
	Count of Not corroded		1	1
NEOF	Count of Corroded			
	Count of Not corroded		3	3
nicked pinion gear	Count of Corroded			
	Count of Not corroded		1	1
no defect found	Count of Corroded			
	Count of Not corroded		1	1
no failure code	Count of Corroded			
	Count of Not corroded		1	1
no failure info	Count of Corroded			
	Count of Not corroded		2	2
out shaft stripped	Count of Corroded			
	Count of Not corroded		1	1
overheated	Count of Corroded			
	Count of Not corroded		16	16
overheated	Count of Corroded			
	Count of Not corroded		1	1
overheated & leak	Count of Corroded			
	Count of Not corroded		1	1
overheating	Count of Corroded			
	Count of Not corroded		1	1
Over heats	Count of Corroded			

	Count of Not corroded		2	2	
Over speed	Count of Corroded				
	Count of Not corroded		1	1	
Over temp	Count of Corroded				
	Count of Not corroded		1	1	
pinion dropped	Count of Corroded	3		3	
	Count of Not corroded	3	2	5	
pinion fell out,	Count of Corroded				
	Count of Not corroded		1	1	
poor condition	Count of Corroded				
	Count of Not corroded		4	4	
poor records	Count of Corroded	2		2	
	Count of Not corroded	2	1	3	
stud misalignment	Count of Corroded				
	Count of Not corroded		1	1	
previously dissmbly	Count of Corroded				
	Count of Not corroded		2	2	
QDR Exhibit	Count of Corroded				
	Count of Not corroded		1	1	
QDR investigation	Count of Corroded				
	Count of Not corroded		1	1	
quill dropped	Count of Corroded	1		1	
	Count of Not corroded	1		1	
scratched	Count of Corroded	2		2	
	Count of Not corroded	2		2	100%
scratched static	Count of Corroded				
	Count of Not corroded		1	1	
scuffed	Count of Corroded	1		1	
	Count of Not corroded	1	1	2	
scuffed gears	Count of Corroded	4		4	
	Count of Not corroded	4	7	11	36%
scuffed gears, leak	Count of Corroded	1		1	
	Count of Not corroded	1	1	2	
severe corrosion	Count of Corroded	1		1	
	Count of Not corroded	1		1	
sleeve mod	Count of Corroded	1		1	
	Count of Not corroded	1		1	
static gouged	Count of Corroded	1		1	
	Count of Not corroded	1	1	2	
static scratched	Count of Corroded				
	Count of Not corroded		2	2	
static scratches	Count of Corroded				

	Count of Not corroded		1	1
structural failure	Count of Corroded			
	Count of Not corroded		1	1
studs	Count of Corroded	1		1
	Count of Not corroded	1		1
studs (SOF)	Count of Corroded	1		1
	Count of Not corroded	1		1
sudden stop	Count of Corroded			
	Count of Not corroded		1	1
suspec overheating	Count of Corroded			
	Count of Not corroded		1	1
tampered with	Count of Corroded	1		1
	Count of Not corroded	1		1
TSOH	Count of Corroded	1		1
	Count of Not corroded	1		1
TSOH 0	Count of Corroded	1		1
	Count of Not corroded	1		1
TSOH 0, damaged studs	Count of Corroded			
	Count of Not corroded		1	1
TSOH 311	Count of Corroded			
	Count of Not corroded		1	1
vibration	Count of Corroded			
	Count of Not corroded		1	1
vibration	Count of Corroded	1		1
	Count of Not corroded	1		1
vibration confirmed	Count of Corroded			
	Count of Not corroded		1	1
vibration, dismbld	Count of Corroded			
	Count of Not corroded		1	1
vibrations	Count of Corroded	1		1
	Count of Not corroded	1		1
(blank)	Count of Corroded	137		137
	Count of Not corroded			
Total Count Corode		226		226
Total Not corroded		89	185	274

total T/I CCAD	411		
corroded with no other fault	137	137/411	33.3%
corroded only	226	226/411	54.9%
% of corroded without other fault		137/226	60.8%
not corroded	185	185/411	45.0%

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APPENDIX D. REQUESTS FOR ADDITIONAL INFORMATION

For additional information or digital copies of the document please email the author at: Danrshort1@netscape.net

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